MESQUITE UTILIZATION 1982

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MESQUITE UTILIZATION - 1982

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FORWARD

The goal of the Mesquite Utilization Research Program is to determine economically beneficial uses for mesquite wood. The purpose of these proceedings is to document "state of the art" presentations given at the Mesquite Utilization Symposium held at Texas Tech University on October 29, 1982.

The Mesquite Utilization Research Program is administered by the Dean of the College of Agricultural Sciences. It is interdisciplinary in nature, involving faculty in the departments of Chemical, Agricultural, and Mechanical Engineering, Animal Science, Range and Wildlife Management, Agricultural Economics, Chemistry and Food and Nutrition. Research projects have been funded in the areas of harvesting, processing, extraction, ruminant and human nutrition, and economics.

Funding for this research program was initiated by the state legislature in 1977 as a part of the special line item for Research in Brush and Weed Control, Swine and Vegetable Production. Appreciation is expressed to all the legislators, ranchers, agricultural chemical companies, administrators and faculty who have made significant contributions to the program. Without all their cooperative efforts and support, little could have been accomplished.

Thank you!!

Robert C. Albin
Associate Dean
Director of Research
College of Agricultural Sciences

EDITOR'S NOTE

The editor wishes to thank all of the authors for providing camera typescripts for these proceedings and asks the indulgence of the reader in overlooking some inconsistencies in style which were necessary for timely printing of the papers. The conclusions reached in these papers are those of the authors' and do not necessarily reflect the position of the institutions involved or of the Mesquite Utilization Program at Texas Tech University.

Harry W. Parker
Professor of Chemical Engineering

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MESQUITE AS A RANGELAND PLANT [1]

Bill E. Dahl [2]

Abstract - In the southwestern U.S., the name mesquite is commonly applied to honey mesquite, western honey mesquite, and velvet mesquite. These species occupy about 34 million hectares of rangeland. Mesquite's geographical range has changed little during the last 150 years but control of fire and intensive grazing by livestock have allowed a dramatic increase in its density. It is adapted to warm, dry, subtropical and tropical climates.

Date of bud burst in the spring may vary as much as six weeks and that seldom occurs until the last spring frost has passed. Apparently mesquite has a cold requirement that, if not met, delays bud burst. Hence late winter warm spells do not initiate spring growth in mesquite. In areas where soil water is not limiting, mesquite is a luxury user of water. However, if growing on a dry site it probably uses less water than herbaceous vegetation adapted to the area. Mesquite standing crop in the Texas Rolling Plains varies from 2 metric tons/ha in sparse stands to 12 and 22 tons in medium and dense stands. Although regrowth after harvesting is conspicuous, annual regrowth seldom equals the annual yields from herbaceous plants.

Mesquite competes strongly with herbaceous vegetation and in Arizona, 60 trees/ha cuts grass production in half, but 60 trees/ha affected grass production little in Texas. However, with a 10% mesquite ground cover, herbicidal control that prevented all trees from sprouting produced 680 kg/ha of extra grass.

Historically, mesquite has been both a valuable asset to mankind and a profit robbing nuisance. It provided food, clothing, shelter, tools, etc. to man in the 1800's and early 1900's. Today it is primarily used for firewood and as food and shelter for wildlife and livestock. Because it competes strongly with desirable forage, most ranchers desire to eliminate it from their rangeland. The beans are considered excellent feed but horses and cattle may suffer serious digestive disturbances and even death from heavy consumption of the beans. The trees provide shade for livestock on often otherwise treeless ranges. Thus, mesquite is a sometimes beneficial pest that even today is mostly misunderstood.

[1] Presented at the Mesquite Utilization Symposium, Texas Tech University, Lubbock, Texas, October 29 & 30, 1982.

[2] Bill E. Dahl is Professor of Range and Wildlife Management, Texas Tech University, Lubbock, Texas.

KINDS OF MESQUITE

Plants commonly called mesquite that occur in the United States are honey mesquite (Prosopis glandulosa Torr. var. glandulosa); western honey mesquite (P. glandulosa Torr. var. torreyana); velvet mesquite (P. velutina woot.) and running or creeping mesquite (P. reptans Benth. var. cinerascens (Gray) Burk.). Honey mesquite is the common mesquite of Texas. Western honey mesquite mostly occurs in far west Texas, southern New Mexico and extreme southeastern Arizona. Velvet mesquite occurs in southern Arizona. Running mesquite, a prostrate form, occurs in south Texas (Rowell 1969). Mesquite utilization studies in the southwest will deal with all but the running mesquite and for brevity's sake they will be referred to collectively as "mesquite" in this paper.

DISTRIBUTION AND GEOGRAPHICAL RANGE

Rangeland containing significant amounts of mesquite in the southwestern United States is estimated at 22.7 million hectares in Texas, 1.62 million in Oklahoma, 9 million in New Mexico and Arizona, and a small portion of southern Utah and California (Fisher 1977). The surface coverage of mesquite increased dramatically during the latter 1800's and early 1900's, but its geographical distribution has changed little during the last 150 years (Johnston 1963). Reasons for increased density of mesquite within its range are much debated. Control of naturally recurring fires, extended drought, changes in pattern and intensity of grazing through introduction of domestic livestock, plant competition, and rodents have most frequently been cited (Humphrey 1958). The commonly held belief that mesquite was introduced into the U.S. from Mexico by migrating buffalo, Spanish horses, etc. (Fisher et al 1959) apparently is no longer promoted as most students of mesquite now believe that it occurred naturally in its present range.

Humphrey (1958) presents a convincing argument that of all of the factors promoted as to why mesquite has increased on many southwestern rangelands, fire is the apparent controlling factor. He points out that many areas protected from both grazing and fire have allowed mesquite and other shrubs to continue to increase in size and density. Thus, absence of domestic livestock, in itself, was not enough to prevent shrub invasion. Climate, rodents and rabbits have in some instances, facilitated shrub invasion, but they do not appear to have been a major factor in wholesale shrub invasion in the southwest. Had fires not periodically swept southwestern grasslands, probably the entire area would have supported a woody overstory long before the first white man arrived in North America.

Fisher (1977) argues that because fires can be shown to kill only a few of the small mesquite plants, and that its dramatic increase parallels the rapid influx of grazing animals, that the grazing influence was the controlling factor. Probably the truth is that both grazing and fire are major controlling influents and we cannot separate the two. Historically, southwestern ranchers have controlled fires to reserve dry grass for dormant season grazing. Many of them also over used their pastures which did not allow enough fine fuel in the form of grass to carry a fire sufficiently hot to kill woody plants. The point is that mesquite is apparently well adapted to most southwestern rangelands and we have unknowingly or unwittingly managed the lands in such a manner that woody vegetation, particularly mesquite, has regained a competitive advantage over the preferred herbaceous plants. From our recent experience, we are not going to easily eliminate mesquite either through burning or through grazing management although a carefully coordinated burning and rotation grazing management program could conceivably do so. The question is, what are we going to do with it? In order to answer that question, we should first understand its biology. Had we understood the biology of mesquite 100 years ago, we might not have avoided the problem we now face, but we might better understand it.

MESQUITE BIOLOGY

SOIL ADAPTATION

Few authors bother to describe the soils inhabited by mesquite because it is considered adapted to all soil types under a wide range of moisture conditions (Parker and Martin 1952). Nearly a century ago Havard (1884) described mesquite's soil adaptability thus "There is hardly any soil, if it is not habitually damp, in which mesquite cannot grow; no hill too rocky or broken, no flat too sandy or saline, no dune too shifting ... to entirely exclude it." While this is generally true for mesquite in Texas, it grows best on medium to fine textured soils. On upland soils mesquite density is highest on the clay loam soils, with fewer trees per unit area as soils become sandier. In west Texas scattered mesquite trees occur on sandy soils with a sandy clay B horizon, but they are generally absent on the deep sands without such a layer. In those areas of west Texas and southern New Mexico where mesquite grows on hummocky sand dunes the sands are not extremely deep. According to Wooten (1915) mesquite is a significant browse plant only on the tight (finer textured) soils of southern New Mexico.

CLIMATE

Mesquite is adapted to warm, dry, subtropical and tropical climates. In the southwestern United States it is limited to altitudes below 5500 feet, and it develops best below 4500 feet. Temperature appears to control its northern boundary as Fisher et al (1959) points out mesquite's northern limit appears to follow the average annual minimum temperature isotherm of -19.5C. Bogusch (1951) suggests that the frequency of years where January mean temperatures lie wholly below 0°C strongly influences mesquite's northern limit. Periodic winter kill of stem base is characteristic for mesquite within its northern range. It is best adapted to areas with 200 or more frost free days (Parker and Martin 1952).

Mesquite's eastern and western limits are difficult to define based on precipitation. Mesquite thrives along drainage ways in the desert where annual rainfall is below 6 inches; it also grows on neutral and alkaline soils where annual precipitation exceeds 30 inches (Fisher et al 1959). Bogusch (1951) believes that high soil moisture and low soil oxygen effectively contains mesquite's spread into increasingly humid areas. However, Peacock and McMillan (1965) provide evidence that high moisture and low oxygen don't necessarily limit mesquite. Their mesquite plants grew poorly in east Texas soil compared to soils from further west regardless of water level in the rooting zone. They concluded that some other physical or chemical soil factor must be limiting mesquite's eastward spread as it can apparently tolerate relatively high soil moisture. It is common knowledge that mesquite cannot survive totally saturated soil but it apparently can tolerate high (but not saturated) soil moisture. The east Texas soil used by Peacock and McMillan was lower in pH but the study did not ascertain whether low pH was the factor limiting growth although it should be considered as one of the suspected factors.

LIFE CYCLE

Seeds and Seedlings

Mesquite seeds are brown, oval, 5 mm wide, 7 mm long and 2 mm thick (Meyer et al 1971). They are borne in a legume fruit (pod) resembling a black-eyed pea pod. Within this pod, a bony, protective covering surrounds each seed and it must be broken before germination can occur. This seed coat is most easily broken during passage through the digestive tracts of animals. Otherwise the seed lies dormant until the seed coat is broken by weathering. Fisher et al (1959) found that 82, 69, and 25% of mesquite seed germinated after passing through horses, steers, and ewes, respectively.

Water uptake during germination is rapid with noticeable swelling of the seed coat within 3 hours after wetting. The primary root emerges within a day and it elongates rapidly for 2 to 3 days while the cotyledons expand slightly and turn from yellow to light green. The primary leaf is usually fully expanded within a week after germination (Meyer et al 1971).

Regardless of seed origin Peacock and McMillan (1965) found that mesquite seeds germinated best at 24C or greater. Haas et al (1973) reported similar optimum germination temperatures and they reported most rapid seedling growth when soil temperatures reached 27 to 32 C. They concluded that optimum physiological activity of mesquite seed occurs at about 30 C. Also, less water was required for germination at optimum temperatures than at either higher or lower temperatures. Rate of water uptake at 21 C was about half that at 30 C.

Light does not regulate mesquite seed germination. Thus, seeds would germinate without soil cover but seedlings did not become established. Mesquite seeds scattered on buffalograss or tobosagrass pastures did not produce seedlings. They only did so when covered by a thin layer of soil or organic debris. However, 5 cm was too deep as seeds planted at that depth produced no seedlings (Haas et al 1973).

Bogusch (1951) indicated that soil surface moisture should persist for 3 to 5 days after germination to insure seedling establishment. Haas et al

(1973) also reported that cool soil temperatures between March 3 and May 15 caused death of 75% of mesquite seedlings with adequate moisture. Greatest survival occurred from May 15 to June 1 with ideal soil temperatures although soil moisture was relatively low.

Although light is not necessary for germination, it is necessary for seedling survival as dense shade usually prevents seedling survival (Bogusch 1951). However, seedlings may survive if the radiant energy is as much as half-full sunlight (Haas et al 1973). Degree of competition from established grasses probably does as much to affect seedling survival as other habitat characteristics. Wright (1972) found that seedlings established in 1969 in buffalograss, tobosagrass or bare areas had 22, 0, and 27% survival after three growing seasons. Because the buffalograss provided little shading to seedlings relative to the tobosagrass, one might assume that the dense foliage and litter of tobosagrass provided too much shade for the mesquite seedlings.

Smith et al (1972) reported that seedling mortality due to water stress was greatest on soils naturally containing few if any mesquite. In their study, this was related to calcium carbonate content of the soil. Water that was available to mesquite seedlings decreased as soil calcium carbonate content increased.

By the time the first true leaves develop, mesquite seedlings have developed buds on the stem in the axil of the cotyledonary leaves. Mesquite seedlings do not survive if tops are clipped below the cotyledons. However, clipping above the cotyledons stimulates branching at the cotyledonary node - even 7 days after seedling emergence (Haas et al 1973).

Juvenile Stage

The juvenile period in mesquite's development lasts for 2 to 3 years depending on growing conditions. It extends from development of the first true leaf after seed germination to production of mature, woody xylem. Optimum soil temperatures for growth are 30 to 32 C as was the case for germination. Juvenile plants may grow from a few centimeters to a meter tall during the first growing season. However, they are relatively susceptible to hot, dry conditions unless their roots extend into the moist lower soil. Under good growing conditions juvenile plants may reach 2 meters in height in 3 years but they do not flower during the juvenile stage (Haas et al 1973).

Mature Plant Stage

Mesquite fully matures after 3 years into either a flowering single-stemmed tree or a flowering many-stemmed shrub. Removal of top growth by freezing, trampling, grazing by insects or other animals, etc. during either the juvenile or mature stage removes apical dominance and new shoots arise from the dormant axillary buds (the "bud zone") at the stem base resulting in the many stemmed shrub. The single-stemmed tree results from unaltered growth during juvenile and later stages.

On branches of trees and shrubs, buds near the stem tip produce leaves, stems and inflorescenses from the same node in the second growing season following their formation. As many as seven leaves, three stems, or six inflorescences have been found from a single node (Meyer 1971). Mesquite thorns are modified stems arising only on new growth. They are subsequently buried in the stem by radial growth (Haas et al 1973). New branches in the canopy increase about 20 to 35% annually on mature trees resulting in an umbrella-like appearance.

Dormant buds occur along the trunks, branches and twigs of mature trees. If a stem is injured or dies, the buds below the injury will produce new stems. Mechanical or chemical treatment that kills or removes the entire above ground portion, but that does not totally kill the plant, gives rise to numerous new stems from the bud zone at the base of the plant, at or below the soil surface. However, mesquite is not a root sprouter. Adventitious buds do not develop from the root tissues and the plant dies if all stem tissues are killed (Fisher et al 1959).

Following spring bud burst twig elongation and leaf growth proceeds rapidly, continuing for about 6 weeks. Twig elongation precedes radial trunk growth and trunk growth is repressed until stem elongation is completed (Haas et al 1973). Root growth occurs during this period but soil temperatures are probably not optimum for maximum root growth until the soil temperature exceeds 24 C (Dahl et al 1971). However, no actual measurements of root growth under field conditions have been done so evidence of root growth is determined indirectly. Miniature inflorescences emerge from buds in the spring along with leaves and new stems with miniature pods developing about the time twig elongation ceases and leaves have reached full size. Fruit development from miniature beans to maturity takes from two to three months and the falling of mature pods from the trees occurs in west Texas in July or August (Goen 1975; and Wilson et al 1975). If a new flush of growth is stimulated by a wet period later in the season, both leaves and inflorescences may emerge from axillary buds. Thus, it is possible to have more than one bean crop from a mesquite plant in a year. Although one hears that three bean crops per year occur, more than one crop is uncommon. Goen (1975) observed 25 trees per site in west Texas for four years and found that only 2% produced as much as 50% of their estimated potential number of beans and only 7% produced 30% of their potential. The few trees that produced beans consistently did so each of the four years whereas most plants produced none or very few.

Following cessation of twig elongation and radial trunk growth (about midsummer) mesquite trees are visually quiescent except for occasional flushes of new leaves stimulated by rainy periods. They are dormant by fall and the trees defoliate generally in November and December by killing frost or insect leaf removal.

VARIATION AMONG PLANTS

All mature mesquite plants growing in the same site respond characteristically to gross seasonal changes, but individual plants often respond differently to date of bud burst, flowering, fruiting load, response to herbicide etc. (Goen 1975; Dahl et al 1971). Obviously, this is due to a multitude of interacting variables, but I believe that much variation among individuals can be explained by differences in rooting depth caused by soils conditions during seedling establishment. For example, herbicidal control of mesquite on sandy soils in southwest Texas from pelleted, soil-applied tebuthiuron gave total plant kill on some plants but adjacent plants were unaffected. Because this herbicide depends on root uptake for effectiveness, it leads me to believe that one plant, during seedling establishment, had good deep soil moisture allowing for deep tap-root penetration. It was not affected in a visible way by the herbicide. On the other hand, we know that despite extreme rooting depth potential, that many mesquite plants do not have a tap root extending more than two or three meters, presumably due to something restricting rooting depth during the establishment phase (often shallow moisture penetration), thus shallow rooted mesquite could get a lethal dose of herbicide but the plant with the deeply penetrating roots would be able to escape.

WHY DOES MESQUITE LEAF OUT ONLY AFTER THE LAST SPRING FROST?

Budbreak in mesquite rarely occurs prior to the last spring frost. In fact, most west Texans consider that the danger of a spring frost no longer exists if mesquite leaves have begun to emerge. Unseasonally warm weather in February and early March usually results in bud burst of ornamental trees and shrubs and fruit trees in the Southwest but never mesquite. What is the mechanism?

The earliest west Texas budbreak in recent years occurred about March 17, 1972 and the latest occurred in early May in 1973 and 1975, fully 6-weeks later than budbreak in 1972 (Goen and Dahl 1982). Many observers have noticed that warm winters delay budbreak of cold climate deciduous trees, and trees or shrubs growing in shade have their chilling requirement satisfied better than those growing in the sun. Apparently, plants that have survived severe winter climates are those that can tolerate a lengthy cold period of below freezing temperatures and if that cold period does not occur or is less severe, budbreak is considerably delayed. This is apparently the case for mesquite. Since 1970 we have monitored many mesquite trees trying to better correlate mesquite mortality from herbicides to stage of growth. Our data showed that the more consecutive cold days (using daily minimum temperatures) occurring from mid-January to mid-February, the earlier budbreak would occur. Once the winter chilling requirements were met, warm temperatures after mid-February hastened the date of budbreak (Goen and Dahl 1982).

MESQUITE ROOTING CHARACTERISTICS

Mesquite's dual root system is well suited to the southwest. Its taproot often penetrates the soil for 5 or more meters. In addition, its extensive lateral roots spread for over 15 meters from the plant's base. Because it can potentially extend its tap root deeply, many discussions of mesquite's rooting depth (Winckler 1982) lead one to believe that all mesquite trees have tap roots extending 12 to 15 meters deep regardless of site occupied. This is not usually possible as we commonly find that mesquite growing on uplands will have taproots extending downward for up to 2 meters and then abruptly bend at right angles due to some soil factor restricting rooting depth. Once this occurs, laterals from the taproot seldom extend more than another meter or two downward. Most commonly rooting depth restriction is due to dry soil or a distinct calcium carbonate layer. Upland fine textured soils in the southwest seldom have soil moistened more than two meters deep, thus it is not possible to have plant roots of even potentially deep rooting perennial trees and shrubs extending more than a meter or two deeper than the common wetting depth for the site. Also, studies designed to define the role of soil characteristics in mesquite distribution indicate that amount of available water is the primary factor affecting mesquite density on the southern high plains (Allen et al 1971). Soil texture, structure, and amounts of calcium carbonate, gypsum, and soluble salts affect water availability to mesquite. These factors also affect rooting depth.

WATER USE AND WATER USE EFFICIENCY

Southwesterners worry about water use by undesirable vegetation particularly when it is commonly reported that ten million acre-feet of water is transpired by undesirable brush in Texas alone. This is more than is used by all the towns, factories, farms, and people (Rechinthin and Smith 1967). Mesquite, because of the many acres it covers, usually heads the list of water users. Mesquite in Arizona used 1725 kg of water to produce a kg of dry matter compared to 400 to 500 kg needed to produce a kg of dry grama grasses (McGinnies and Arnold 1930). In New Mexico, mesquite used 1432 kg of water to produce a kg of dry matter (Degarmo 1966). These were pot studies which may have no bearing on field water use. Sims et al (1976) found water used by grasses in Colorado to be over 1620 kg per each kg of dry matter produced during optimum growth periods. Water use efficiency decreased with increasing maturity and as soil water declined. Presumably mesquite's water use efficiency would vary also under field conditions with stage of growth and growing conditions. Probably greenhouse pot studies of water use are poor guides to a plants actual water use in the field.

Wendt et al (1968) studied mesquite seedling transpiration rate at various soil moisture levels and found that soil moisture differences affected transpiration rate very little but that as the evaporating potential of the atmosphere increased transpiration rate decreased. They concluded that mesquite has some mechanism to reduce transpiration with high atmospheric evaporation. Thomas (1976) found that in mature field trees transpiration was definitely influenced by soil water content in addition to atmospheric conditions. On dry sites, mesquite reduced transpiration when evaporation demand was greatest, e.g. in the afternoon. However, on the same days, if these sites were irrigated, trees continued transpiring at an almost constant rate. Transpiration rates followed a distinct daily pattern on both wet and dry sites. Transpiration started about sunrise, was at a maximum at noon, decreasing slowly until two hours before sunset when transpiration sharply decreased. No transpiration occurred at night. Transpiration of trees growing where soil water was limited was maximum before noon and the rate decreased more rapidly throughout the remainder of the day.

To find out dependence on the tap root for water, Thomas (1976) cut the tap root on some plants and left it intact on others. During the first year, soil water was limited and trees with cut and uncut tap roots transpired less on non-irrigated sites. The second year had more rainfall and no differences were noted due to irrigation or lack of it. During the dry year, trees with cut tap roots defoliated and recovered slowly on the non-irrigated site but the irrigated trees showed no detrimental effects. On the dry site the trees with cut tap roots transpired less. He concluded that when soil water is not limiting, mesquite trees depend primarily on lateral roots in the upper 60 cm of soil. When soil water is limited in the upper 60 cm, mesquite depends on the tap root for its survival. This probably explains why mesquite shows little sign of moisture stress during most droughts.

Thomas (1976) found no differences in transpiration rates due to location within stand or whether stands had been thinned. Thus, thinning a stand to reduce transpiration rates per tree may not be feasible.

Easter and Sosebee (1975) also studying water-use by mesquite concluded that amount of soil water lost via mesquite depends on the environment in which it grows as did Thomas (1976). In areas where soil water is not limiting, such as in bottomland sites, along streams, and during high rainfall years, mesquite is probably a luxury consumer of water and its control would increase water yield to other uses. However, if mesquite is growing on a dry site, mesquite control may not yield an increase in soil water during many years. Surprisingly, Thomas (1976) found that range grasses and crops grown in the same environment with mesquite started transpiring earlier, maintained higher rates during the day, and continued transpiring longer than any of the mesquite trees.

We can conclude that mesquite control for conserving water is much more effective in areas where the trees have access to a plentiful supply of water. There are many examples of springs drying up as mesquite density increased. In the San Angelo area, the Rocky Creek (a tributary of the Middle Concho River) watershed had several thousand acres cleared during the late 1950's and the early 1960's. The clearing was primarily by individual dozing out of trees. This creek had not flowed except during flooding situations for many years according to local residents. Within 5-years after the clearing (about 1965 to 1967) this creek became a perennial flowing stream which continues to flow year-round through wet and dry years to this day. Thus, judicious, well chosen mesquite control programs can yield extra water to landowners as well as downstream users including municipalities.

Bedunah (1981) studied method of control on water saving in the Texas Rolling Plains and concluded that all mesquite control techniques increased herbage production compared to no control but soil water did not always increase because the added water was immediately used by the available plants. He studied herbicidal control, shredding, individual tree grubbing, clearing and seeding to kleingrass, and tree grubbing and vibratilling (chiseling). The treatments that mechanically disturbed the soil decreased runoff from intense thunderstorms. Vibratilling allowed for improved water infiltration and deeper water percolation. Shredding increased water infiltration, decreased mesquite competition for water, and added considerable litter to the soil. However, 3 years after shredding mesquite regrowth was enough to again retard grass growth.

To find out whether grubbing out individual trees allowed for more available soil moisture for grass use and for producing water off site, one treatment was to excavate pits between trees similar to the pit excavated from grubbing out the tree. The idea was to test whether the increased stream flow in Rocky Creek was due to mesquite removal or to the thousands of pits created by digging out the mesquite. Bedunah (1982) found little extra benefit from excavating the pits without the tree removal, either in extra stored water or in extra forage production. Therefore, the ground water available for increasing stream flow and to grow more grass due to mesquite removal is presumed due mostly to the actual mesquite removal which removed water loss through transpiration.

POTENTIAL MESQUITE BIOMASS AND YIELD

Because we have been mostly interested in increasing forage for animals through killing, thinning or removal of mesquite, few measurements of mesquite standing biomass and regrowth exist. Recently, the idea that mesquite wood may be commercially useable has increased interest in its potential yield. Mesquite wood can be used as a protein source for livestock, as flooring material, for wood pulp, for charcoal, as a fuel, etc. Yield estimates are needed for these purposes as well as for predicting spread and intensity of wildland fires.

Whisenant and Burzlaff (1978) found a close correlation between stem area at 60 cm above ground and green weight of mesquite trees. They found green weight of mesquite on typical virgin stands in the Texas Rolling Plains of 4.1, 19.4, and 36.1 metric tons per ha for shallow soils, deep upland soils, and bottomland areas, respectively. These stands had an average of 259, 567, and 633 trees/ha. It is hard to convert green weight to dry weight as sapwood is much higher in moisture than heartwood and the trees contain differing amounts of each kind of wood. Hearron (1972) found green mesquite wood, 3 to 5 cm in diameter, contained 55 to 67% water on a dry weight basis (35-40% on a wet basis) and he estimated that regrowth with only sapwood would have 86% water. Mesquite trees in the area would have many stems larger than 5 cm, which would have more heartwood. Thus, if we assume 40% water content (wet basis), then Texas mesquites standing biomass can be expected to be about 2, 12, and 22 metric tons/ha of dry wood on the shallow upland, deep upland, and bottomland sites. Marion et al (1957) reported that 2600 trees/ha produced over 8 metric tons of oven-dry wood. Their trees were undoubtedly smaller and more numerous than the above quoted figures but the yield per ha compares favorably. The Soil Conservation Service's 1973 Brush Survey showed that the Rolling Plains land resource area in Texas had 1,486,630 ha of sparse, 2,063,309 ha of medium, and 1,831,544 ha of dense stands of mesquite (Whisenant and Burzlaff 1978). If we assume that these sparse, medium, and dense stands are roughly related to the shallow upland, deep upland, and bottomland areas, then we have a crude estimate of the standing mesquite biomass in the Texas Rolling Plains.

The biomass values quoted for this one resource area indicate the potential one-time yield, but how about regrowth potential? Wright and Stinson (1970) cut mesquite trees twice a month in 1967 and 1968 in the Rolling Plains and measured the regrowth after one growing season. Top removal reduced regrowth at least 75% during all seasons. Tops removed in May when carbohydrate storage was lowest, reduced regrowth the most. Current year's growth on uncut trees was about 1.8 kg vs about 0.4 kg on trees with tops removed. If a site had 600 trees/ha this would be 1080 kg/ha on uncut trees vs 240 kg/ha on cut trees.

Herndon (1975), in the Texas Rolling Plains, found that mesquite regrowth shredded off each year in May for 5 years produced only 28% as much as unshredded mesquite. If the shredding interval were 2 years the annual regrowth was 44% of controls; if 3 years, regrowth was 57%; if 4 years, 62%; and mesquite produced 66% as much as the unshredded mesquite if allowed to regrow for 5 years. Regrowth per year was about 730, 210, 320, 420, 460, and 480 kg/ha, respectively for unshredded trees, and trees shredded each year, each two years, each 3 years, each 4 years, and each 5 years. Although, number of trees/ha were not given, 500 to 1000 trees/ha are common in the area concerned.

In other research at Texas Tech we have measured regrowth on some sites in dense stands in bottom areas where the regrowth after top kill or top removal exceeded the current year's growth on untreated mature trees. Thus, if one is interested in harvesting regrowth mesquite, it would be well to choose bottom sites with deep soil and a good soil moisture supply and make the harvest date other than May. Otherwise, the annual mesquite regrowth probably will be considerably less than the annual herbaceous plant growth for the area.

MESQUITES INFLUENCE ON LIVESTOCK AND FORAGE PRODUCTION

Increases in forage and animal production following mesquite control have been consistently reported from research in Arizona and Texas. However, the benefits of mesquite removal were not always positive, so it is incumbent on those planning mesquite control and management programs to take advantage of research conducted for many years in the southwest so that control measures are applied only on those areas and by those methods most likely to meet the objectives of the control. Results of mesquite removal on forage production have been more consistently positive in Arizona than Texas.

At the Santa Rita Experimental Range, with 36 cm of annual precipitation, density and yield of perennial grasses was double that of untreated range within 3 years after killing velvet mesquite on a study conducted from 1940-48. Annual grasses produced over five times that on untreated areas after mesquite elimination. Mesquite seriously competed with grass with only 37 plants/ha and researchers in charge concluded that effective control would require that mesquite density be reduced below this 37 plant/ha density. They found the relationship between decreasing ground cover of perennial grasses and increasing mesquite crown cover to be nearly linear. Eliminating 250 mesquite trees/ha provided enough extra forage to produce 366 kg of beef/km^2 annually (Parker and Martin 1952).

Cable and Martin (1964) found that perennial grass production on the Santa Rita Experimental Range increased over twice as much from 1957 to 1961 (497 vs 247 kg/ha) on mesquite killed units as on the mesquite alive units. However, this substantial increased grass yield was much less dramatic than the similar studies reported from the same area by Parker and Martin (1952). Differences in the two studies were accounted for by indicating that the more recent study was conducted with a more sparse stand of mesquite and a better stand of perennial grass at the start of the study. The implication is that forage production is enhanced more by mesquite control if the mesquite stand is relatively dense and the understory vegetation relatively sparse than if a good stand of perennial grass understory occupies the mesquite understory at the time of mesquite control. Work in Texas with honey mesquite control provides a similar conclusion (Dahl et al 1978). Stocking rates on mesquite-killed units on the Arizona studies increased 169% between 1954 and 1961 compared to a 62% increase on mesquite-alive units. Mesquite were killed by basal application of diesel oil.

On another study from the Santa Rita Experimental Range, mesquite was thinned in 1945 to leave 0, 22, 40, and 62 trees/ha compared to an unthinned stand. Similar plots were established at 4 elevations from 960 to 1250 m. Killing all mesquite trees increased grass yields several fold at all four acreages. Yields on plots with 40 and 62 trees/ha were about half as great as on those with no mesquite. In 1958, 14 years after treatment, plots without mesquite yielded from 4 to 10 times more grass than unthinned plots. Relative forage increases were greater from mesquite thinning at the lower elevations, i.e. the drier areas. But, the increase at these drier sites was mostly annuals (Martin 1963). This data vividly shows that although thinning mesquite increases forage, a relatively few mesquite trees (62/ha) still substantially reduces forage yields in the semiarid southwest compared to total eradication.

More recent studies on the Santa Rita Experimental Range provide additional evidence to support the contention that mesquite severely restricts production of herbaceous plants. Martin et al (1974) compared untreated range to similar range that had been chained in 1970 and to a third area with mesquite controlled by basal oiling with diesel oil. By 1971 mesquite control had not significantly increased yield of annual grasses, but perennial grass production on the mesquite-free tract was more than twice that of the other two areas. Bush muhly (<u>Muhlenbergia porteri</u>) and the <u>Sporobolus</u> sp. increased remarkably on the mesquite-free range.

The Arizona researchers aerially sprayed velvet mesquite dominated range (about 556 trees/ha) with 2,4,5-T in 1954 and again in 1955. Also, Lehmann lovegrass (<u>Eragrostis lehmanniana</u>) was seeded without seedbed preparation on the 40 ha herbicide treated area and a similar 40 ha untreated area. Grass production increased dramatically on the sprayed area during the first 5 years. Native grass production averaged 685 lb/acre compared to only 299 lb/acre on the unsprayed area. After 20 years, the sprayed area still produced significantly more grass than the unsprayed area. Thus, they concluded that it would be better to control mesquite on a similar undisturbed area than to re-treat this area, even after 20 years. Cattle stocking rate was 10.2 head/259 ha (section) from 1943-1953 before treatment compared to 21 head/259 ha (section) for the study period. However, two factors should be mentioned here--1) the early years of the study were unusually wet; and 2) on treated areas a relatively sprase remnant stand of native grasses quickly reoccupied the site with the favorable conditions so seeding would not have been necessary. Over time, the Lehmann lovegrass out-competed the native grasses to where the natives only comprised 10 to 20% of the grass stand.

These studies leave few doubts that velvet mesquite severely restricts grass production in that portion of Arizona serviced by the Santa Rita Experimental Range. Also, the studies indicate that broadcast herbicidal control that does not harm understory grasses would provide increased grass production similar to other means of control--of course this would be commensurate with the degree of control obtained.

Work by Cable (1977) on soil water use by velvet mesquite provides probably the best explanation why velvet mesquite is so competitive with grasses. He found that mesquite used water consistently to a depth of 3 m and outward to 10 m beyond the crowns (canopy) but use at 15 m beyond the mesquite canopy was limited mainly to drier periods when water supplies closer to the trees were depleted. The competitive effect of velvet mesquite on perennial grasses was most severe in the upper 37.5 cm of soil under and near the mesquite crowns (canopy), and gradually decreased with distance into adjacent openings. The competitive effect in the openings was much more severe in dry than in wet years.

As in Arizona, research in Texas to evaluate benefits of mesquite removal to forage and animal production has been conducted since the mid 1940's. Grazing trials with yearling steers were conducted at Spur during the summers from 1945 to 1954 on 8 pastures-four without mesquite control and four cleared of mesquite by removing the tops and treating the stumps. Sprout growth was controlled at 5-year intervals by aerial spraying of 2,4,5-T. During the 10 years, steers averaged 93 vs 79 kg of gain for the cleared and uncleared pastures. Summer stocking rates was 2.6 ha/head for an annual grazing period of 156 days (Fisher et al 1959). Note that they maintained the same stocking rate for both treatments.

Robison et al (1970) reported on another facet of the same Spur study conducted from 1960 to 1968 with cows and calves. During 8 years, weaning weight of calves on brush pastures averaged 217 vs 232 kg for calves on mesquite cleared pastures. Greater differences in weaning weights occurred in years when growing season rainfall was limited or poorly distributed. Easier handling of cows and calves was another plus for the cleared pastures. Forage yields obtained in 1968 showed that cleared pastures produced 472 kg/ha more forage than adjacent brush pastures. Their data also showed that mesquite control was more beneficial to the better forages, i.e. sideoats grama (*Bouteloua curtipendula*) and silver bluestem (*Andropogon saccharoides*) than to increaser species such as buffalograss (*Buchloe dactyloides*).

On pasture-scale studies conducted on 7 ranch locations throughout west Texas, Fisher (1975) reports that calf gain increased 15 kg/head on pastures aerially sprayed with 2,4,5-T and that labor required to gather and handle cattle was reduced 50% on cleared pastures. Cross et al (1976) reported from 3 of the ranchers from the same study that calves weaned at 246 kg (318 calves) on 2,4,5-T sprayed pastures compared to 235 kg (311 calves) on untreated pastures from 1969 to 1974. Robison et al (1970) reports forage yields from the Matador Ranch, Matador, Texas (one of the ranches included in the above reported study) in 1968. The average oven-dry forage production (sampled in August) on the pasture sprayed with 2,4,5-T 14 months previously, was 2225 vs 1517 kg/ha on the uncleared pasture. The higher producing forage species responded proportionately better to mesquite removal.

Workman et al (1965) reported from a survey of ranchers in the eastern part of the Texas Rolling Plains, that grazing capacity on upland sites was increased from 8.9 to 6.9 ha/AU/year, and from 8.1 to 6.9 ha/AU/year on bottomland sites following aerial spraying with 2,4,5-T. The estimated grazing rate on the upland site peaked at 1.75 AUM's/ha the first year after spraying and it began to decline the fourth year. Grazing rate peaked on bottomland sites at 1.80 AUM's/ha 1 year after grazing and began to decline 3 years after spraying. Results of these interviews gave surprisingly similar results to research reported from the area.

The only Texas study found relating grass yield to mesquite density or canopy cover was conducted by Dahl et al (1978) from 1970 to 1975 in west Texas. Just as reported by Workman et al (1965), their data showed peak grass response the year after spraying. However, rather than a steady decline, increased forage was seemingly related to climate during the year. For example, grass yield increased only 2% the second year after spraying over unsprayed plots compared to 26% increased grass yields due to 2,4,5-T spraying the third year after treatment. Grass yields dramatically increased with both reduced mesquite canopy cover and with increased proportion of plants apparently killed the year of 2,4,5-T application. Overall, this study showed that 2,4,5-T spraying increased perennial grass yields 22% for the 5 years included. From a similar study with mesquite sprayed in 1969 or 1970 at four ranch locations, grass yields in 1971 were 63% greater on aerially sprayed pastures (Fisher et al 1972).

Freeman et al (1978) attempted to show economically the value of mesquite control to a ranching enterprise in the Texas Rolling Plains. Their analysis showed that rancher income could be significantly enhanced if mesquite control could provide as much as 21% increased forage production over 7 years. From the articles reviewed, one could reasonably expect the 21% grass increase for 7 years in west Texas.

In south Texas, 2,4,5-T appears less useful than combinations of herbicides because of the regrowth of brush species not well controlled by 2,4,5-T alone. Nevertheless, preliminary indications from Scifres et al (1977) are that even there, 2,4,5-T increases grass production the first year after spraying. Production of native grasses following aerial application of 1.12 kg/ha of 2,4,5-T, 2,4,5-T + dicamba, or 2,4,5-T plus picloram to a mixed brush (Prosopis-Acacia) community was significantly increased by all herbicide treatments the year of application, by the herbicide combinations during the second year, but only by 2,4,5-T plus picloram the third year after treatment. Defoliation of woody plants in years of above-average rainfall resulted in favorable grass production regardless of herbicide. Forb production was reduced by all herbicides the year of treatment and by 2,4,5-T plus picloram the year following application, but was not reduced by any treatment during the third growing season.

Mesquite infested rangelands in west Texas apparently produce about 1230 kg/ha of grass by mid-summer. Rangeland with mesquite controlled by 2,4,5-T can be expected to produce about 1680 kg/ha by mid-summer. Although increased grass production was usually greatest the year after spraying, extra production of about this magnitude can be expected for an average of 4 years or more (Workman et al 1965; Robison et al 1970; Fisher et al 1972; Dahl et al 1978). Whereas Martin (1963) reported that as few as 35 to 60 velvet mesquite trees/ha in Arizona could reduce grass production by half, 60 mesquite trees/ha in west Texas apparently has little influence on perennial grass production (Dahl et al 1978).

Nevertheless, the degree of mesquite kill obtained by herbicide application is extremely important in providing extra grass production. Dahl et al (1978) showed that with a honey mesquite canopy of only 10% that if as many as 30% of the trees began sprouting the year of 2,4,5-T application no extra grass was produced. If the spray prevented all trees from sprouting, 680 kg/ha of extra grass could be expected. On the other hand, with a 50% mesquite canopy, 30% of the trees could resprout the year of application and one could still expect 680 kg of extra grass/ha over a 4 year period. The Dahl et al (1978) research showed that an average of 24% of the 2,4,5-T sprayed mesquite trees resprouted by fall of the year sprayed and that 19% of the trees were permanently killed. These values are probably very close to the long time average of 2,4,5-T sprayed honey mesquite trees throughout the High and Rolling Plains of Texas. While paying for this amount of honey mesquite control when cattle prices are low strictly from extra forage production would be marginal, both Freeman et al (1978) and Workman et al (1965) indicate that it would be very worthwhile if calf prices are as much as $1.10/kg. If one considers that many ranchers consider the labor savings in gathering and handling livestock worth $2.50/ha (Hoffman 1975), that mesquite uses and transpires about 43% of the rain falling on the Rolling Plains of Texas (Gillette 1967), and that Texas brush uses more water annually than is presently used by all industrial and municipal purposes (Rechinthin and Smith 1967), it is easily understood why mesquite control is an important topic in Texas. Because velvet mesquite inhibits grass production more in Arizona than honey mesquite does in Texas, it is also easy to see why mesquite management and control has had high priority also in Arizona. Based on the lack of available literature, role of mesquite on forage yield and livestock production has been little researched in New Mexico. However, the principles from Texas and Arizona research should apply reasonably well to mesquite infestations in New Mexico.

ANIMAL USE OF MESQUITE

Historically mesquite was a valuable plant to the Indians, Mexicans, and white pioneers during the 1800's and early 1900's as it provided food, clothing, shelter, tools, and many other items. Today it is primarily useful as firewood and as food and shelter for wildlife and livestock (Langford 1969).

A search of the literature by Langford (1969) revealed that quail, dove, raven, turkey, and ducks are a few of the birds known to use mesquite beans as a food. Rodents, such as the wood rat, kangaroo rat, chipmunk, pocket mouse, ground squirrel and the prairie dog eat mesquite seeds and store the pods in their burrows. Cottontail rabbits, jack rabbits, skunks, peccaries, the Mexican raccoon and coyotes depend on mesquite for a portion of their food. The bark is one of the jack rabbit's chief foods during the winter and spring.

Mesquite continues to be a source of food and shelter for all kinds of livestock. The bean pods are high in sugars and before totally becoming dry they are quite sweet to the taste and they are relished by cattle, horses, sheep, goats, hogs, mules, and burros. One student told me that catfish also like them and I don't doubt it. The pods are eaten whole or in large pieces, but the small, hard seeds contain much of the nutrients which largely pass undigested through the animals. Therefore, mesquite fruits or pods are a better feed if ground into a meal. Although some use of leaves is made by grazing livestock and wildlife, our diet studies over several years show that the leaves are rarely eaten so we do not consider mesquite foliage as an important food source.

Although mesquite beans are usually considered excellent feed, horses and cattle may suffer serious digestive disturbances and even death from heavy consumption of the beans. Jaw and tongue trouble can be produced in cattle from the beans and they frequently remain in the digestive tract for 3 months and some as long as 9 months (Dollahite and Anthony 1957).

Mesquite trees provide shade for livestock on often otherwise treeless ranges. They also shelter livestock against wind, rain, snow, and hail. The trees are indispensible in many areas as shade and cover for wildlife.

LITERATURE CITED

Allen, B. L., W. Hudnall, and C. T. Hallmark. 1971. Effects of soil properties on brush distribution. Page 16. In Texas Tech Univ. Noxious Brush and Weed Control Research Highlights - 1971. ICASALS Special Rept. No. 51. 35p.

Bedunah, D. J. 1982. Influence of some vegetation manipulation practices on the bio-hydrological state of a depleted deep hardland range site. Ph.D. Dissertation, Texas Tech University. Lubbock, Texas. 188p.

Bogusch, E. R. 1951. Climatic limits affecting distribution of mesquite (*Prosopis juliflora*) in Texas. Texas J. Sci. 3:554-558.

Cable, D. R. and S. C. Martin. 1964. Forage production and stocking rates on southern Arizona ranges can be improved. USDA Rocky Mtn. Forest and Range Exp. Sta. Res. Note RM-30. 11p.

__________. 1977. Seasonal use of soil water by mature velvet mesquite. J. Range Manage. 30:4-11.

Dahl, B. E., R. B. Wadley, M. R. George, and J. L. Talbot. 1971. Influence of site on mesquite mortality from 2,4,5-T. J. Range Manage. 24:210-215.

__________, R. E. Sosebee, J. P. Goen, and C. S. Brumley. 1978. Will mesquite control with 2,4,5-T enhance grass production? J. Range Manage. 31:129-131.

Degarmo, C. H. 1966. Water requirement and production of eight desert plant species under four soil moisture levels. M.S. Thesis. New Mex. State Univ. Las Cruces, New Mex. 63p.

Dollahite, J. W., and W. V. Anthony. 1957. Malnutrition in cattle on an unbalanced diet of mesquite beans. Tex. Agr. Exp. Sta. PR-1931. 4p.

Easter, S. J., and R. E. Sosebee. 1975. Influence of soil-water potential on the water relationships of honey mesquite. J. Range Manage. 28:230-232.

Fisher, C. E., C. H. Meadors, R. Behrens, E. D. Robinson, P. T. Marion, and H. L. Morton. 1959. Control of mesquite on grazing lands. Texas Agr. Expt. Sta. Bull. 935. 24p.

__________, H. T. Wiedemann, J. P. Walter, C. H. Meadors, J. H. Brock, and B. T. Cross. 1972. Brush control research on rangeland. Texas Agr. Ext. Ser. Misc. Publ. MP-1043. Texas A&M Univ. College Station. 18p.

__________. 1975. Cooperative brush control research on rangeland. P. 20. In Univ. Texas Coop. Field Day and Tour. 45p.

__________. 1977. Mesquite and modern man in southwestern North America. Pages 177-188. In Simpson, B. B. (ed.). Mesquite - its biology in two desert shrub ecosystems. Dowden, Hutchinson and Ross, Inc. Stroudsburg, Penn. 250p.

Freeman, B. G., G. T. Richardson, Jr., B. E. Dahl, and E. B. Herndon. 1978. An economic analysis of mesquite spraying in the Rolling Plains of Texas. College of Ag-Sci. Pub. T-1-77. Texas Tech Univ. Lubbock. 41p.

Gillette, J. 1967. Brush: The water thief. Supplement to the San Angelo Standard - Times. San Angelo, Texas. 23p.

Goen, J. P. 1975. Influence of environment on mesquite phenology. M.S. Thesis. Texas Tech Univ. Lubbock, Texas. 95p.

__________, and B. E. Dahl. 1982. Factors affecting budbreak in honey mesquite in west Texas. J. Range Manage. 35:(in press).

Haas, R. H., R. E. Meyer, C. J. Scifres, and J. H. Brock. 1973. Growth and development of mesquite. Pages 10-19. In Mesquite growth and development, management, economics, control, uses. Texas Agr. Expt. Sta. Res. Monog. 1. 84p.

Havard, V. 1884. The mezquit. Amer. Natur. 18:451-459.

Hearron, G. S. 1972. A mathematical model of photosynthate transport in phloem of mesquite. M.S. Thesis. Texas Tech Univ. Lubbock, Texas. 78p.

Herndon, E. B. 1975. Shredding for mesquite control. Page 14. In Wright and Sosebee (eds.). Texas Tech Univ. Noxious Brush and Weed Control Research Highlights - 1975. Vol. 6. 46p.

Hoffman, G. O. 1975. Mesquite control. Texas Ag. Ext. Ser. Misc. Pub. MP-386. Texas A&M Univ. College Station. 10p.

Humphrey, R. R. 1958. The desert grassland. Botan. Rev. 24:193-272.

Johnston, M. C. 1963. Past and present grasslands of southern Texas and northeastern Mexico. Ecology 44:456-466.

Langford, R. A. 1969. Uses of mesquite. Pages 20-22. In Literature on the mesquite (Prosopis L.) of North America, an annotated bibliography. Texas Tech Univ. ICASALS Special Report 46. 84p.

Marion, P. T., C. E. Fisher, and E. D. Robinson. 1957. Ground mesquite wood as a roughage in rations for yearling steers. Texas Agr. Exp. Sta. PR-1972. 4p.

Martin, S. C. 1963. Grow more grass: By controlling mesquite. Prog. Agri. in Ariz. 15(4):15-16.

______________, J. L. Thamus, and E. B. Fish. 1974. Changes in cactus numbers and herbage production after chaining and mesquite control. Prog. Agr. in Ariz. 26(6):3-6.

McGinnies, W. G. and J. F. Arnold. 1939. Relative water requirements of Arizona range plants. Ariz. Agr. Expt. Sta. Tech. Bull. 80. 81p.

Meyer, R. E., H. L. Morton, R. H. Haas and E. D. Robinson. 1971. Morphology and anatomy of honey mesquite. USDA Agr. Res. Serv., Tech. Bull. 1423. 185p.

Parker, K. W. and S. C. Martin. 1952. The mesquite problem on southern Arizona ranges. USDA Circ. 908. 7p.

Peacock, J. T. and C. McMillan. 1965. Ecotypic differentiation in Prosopis (mesquite). Ecol. 46:35-51.

Rechinthin, C. A. and H. N. Smith. 1967. Grassland restoration. Part V. Effect on water yield and supply. USDA Soil Conserv. Service Report. Temple, Texas. 46p.

Robison, E. D., B. T. Cross, and P. T. Marion. 1970. Beef and forage production following honey mesquite control on the Texas Rolling Plains. PR 2803, P. 15. In Brush Research in Texas, 1970. Texas Agr. Exp. Sta. Cons. PR 2801-2828. Texas A&M Univ. College Station.

Rowell, C. M. 1969. The taxonomy and phytogeography of the genus Prosopis L. Pages 4-19 In J. L. Schuster (ed.). Literature on the mesquite (Prosopis L.) of North America an annotated bibliography. ICASALS Special Report No. 26. Texas Tech Univ.

Scifres, C. J., G. P. Durham, and J. L. Mutz. 1977. Range forage production and consumption following aerial spraying of mixed brush. Weed Sci. 25:48-54.

Sims, P. L., B. E. Dahl, and A. H. Denham. 1976. Vegetation and livestock response at three grazing intensities on sandhill rangeland in Eastern Colorado. Colo. Agr. Expt. Sta. Tech. Bull. 130. 48p.

Smith, L. L., D. N. Ueckert, B. L. Allen, and R. D. Pettit. 1972. Effect of soil properties on mesquite seed germination and seedling survival. Page 26. In Wright (ed.). Texas Tech Univ. Noxious Brush and Weed Control Research Highlights - 1972. Vol. 3. 38p.

Thomas, G. W. 1976. Mesquite leaf diffusive resistance under various environmental conditions. M.S. Thesis. Texas Tech Univ. Lubbock, Texas. 53p.

Wendt, C. W., R. H. Haas, and J. Runkles. 1968. Influence of selected environmental variables on the transpiration rate of mesquite (Prosopis glandulosa var. glandulosa (torr.) Cockr.) Agron. J. 60:382-384.

Whisenant, S. G. and D. F. Burzlaff. 1978. Predicting green weight of mesquite (Prosopis glandulosa Torr.). J. Range Manage. 31:396-397.

Wilson, R. T., B. E. Dahl, and D. R. Krieg. 1975. Carbohydrate concentrations in honey mesquite roots in relation to phenological development and reproductive condition. J. Range Manage. 28:286-289.

Winckler, S. 1982. Mesquite-the tree that made Texans tough. Texas Monthly. Sept. page 130.

Wooten, E. O. 1915. Factors affecting range management in New Mexico. USDA Bull. 211. 39p.

Workman, D. R., K. R. Tefertiller and C. L. Leinweber. 1965. Profitability of aerial spraying to control mesquite. Texas Agr. Ext. Serv. Misc. Pub. MP-784. Texas A&M Univ., College Station. 12p.

Wright, H. A. and K. J. Stinson. 1970. Response of mesquite to season of top removal. J. Range Manage. 23:127-128.

____________. 1972. Mesquite seedling competition study. Page 14. In Wright (ed.). Texas Tech Univ. Noxious Brush and Weed Control Research Highlights - 1972. Vol. 3.

ECONOMICS AND TECHNOLOGY OF HARVESTING WHOLE-TREE MESQUITE [1,3]

Willie L. Ulich [2]

Abstract - Due to its physical growth patterns, mesquite is one of the more difficult plants to harvest. A major problem of utilization has been the high cost of harvesting. The challenge was to develop a machine that would reduce the cost of harvesting, not alter the soil surface, nor destroy the grass on mesquite infested rangelands.

Economic design criteria indicated a mobile harvester to cut the tree near the soil surface, retain the whole-tree, cut into small pieces or chips, convey, elevate into a basket, and be able to dump into transport vehicles. This criteria led to experimentation and the development of a mesquite combine.

Field tests indicate the machine meets the initial requirements, can be operated from 1 to 3 mph in light to heavy infestations, and harvest 3 to 5 tons per hour. At lower speeds, tree trunks 6 to 7 inches in diameter can be harvested. Over 85% of the material is maintained and cut into pieces no greater than 3/4 inches in diameter and 7 inches in length. The current cost of harvesting mesquite with this machine is estimated to be $7.46 per green ton which is approximately 50% of other methods being utilized.

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INTRODUCTION

Millions of acres in the United States are endowed with an abundance of wood brush, most of which is considered a hinderance as it robs the soil of moisture, plant nutrients and sunlight from desirable plants. The types of brush varies from yaupon and scrub oaks to mesquite. Reports indicate there are over 50 million acres infested with mesquite in Texas alone. It has been estimated that the density of this mesquite varies from 5 to 20 tons per acre. Much energy and many dollars are expended to remove brush in the state for improved production of such lands. It is estimated that currently only 3-6% of the mesquite cut is utilized. Although there are over 70 known uses, current utilization is mainly for firewood, fence posts and domestic uses. Some of the estimated 4 billion tons of mesquite in Texas could be changed from a nuisance to a valuable resource by way of developing new technology in the utilization as feeds, building materials, or as an energy source. I am optimistic of such development.

Although some uses of mesquite, such as gun stocks, flooring and bowl ware, requires selective harvesting; our selected approach has been toward higher volume utilization. Undoubtedly the limited utilization of mesquite has been due, in part, to the difficulty and resulting high cost of harvesting. The physical characteristics of the mesquite tree consists of crooked trunks and branches, many of which grow at a low angle to the soil surface and the normal sharp thorns. It is undoubtedly one of the most difficult of our plants to harvest. Due to the structure of the mesquite tree, harvesting in chip form appears to be the most practical and economical method. This method allows the whole-tree concept, has minimum waste, and provides for volume harvesting.

CURRENT METHODS OF HARVESTING

Current literature indicates the harvesting of mesquite is being accomplished, almost exclusively, by axe and/or chain saws. Whether mesquite is being utilized for charcoal, barbecue flavor chips, fence posts, or firewood, the mesquite is harvested from standing trees or from windrows formed in a mesquite removal clearing operation. Bulldozer and grubbing operations to clear mesquite land, usually requires pushing or raking the material one or more times into a windrow, where the material is burned as a removal method.

Similar whole-tree harvesting operations information was obtained on the harvesting of cedar and slash timber. A whole-tree cedar harvesting operation, for obtaining cedar oil, was observed at Junction, Texas. The initial operation consists of using small 4-W drive tractors mounted with hydraulic shears which cut individual trees near the ground. Upon drying, the trees are loaded onto a special truck with a front-end tractor loader. Some of the specially built trucks have their own crane by which the trees are loaded. The specially built trucks then haul the trees to an onsite control location where a semi-portable chipper is located. The chipper may have its own loading device, chip up the trees and blow the chips into a van type trailer truck. The trucks then transport the chips to a central processing plant.

The slash wood operation at Diboll, Texas uses large brush and small hardwood trees to make fiber board and particle board building products. In this operation the material is cut by axe and chain saws and the material is carried to an onsite chipper by means of track type tractors with grappling hooks. The chipper blows the chip into a van type truck which transports the chips to the processing plants. It is estimated that the current cedar harvesting operational cost is approximately $15.63/ton and the slash operation $14.82/ton from standing tree to processing plant. Both of these harvesting operations have near a million dollars invested in specialized equipment.

There are now some half dozen wood chippers on the market built primarily for the forest industry (Chamlee 1976, Harrison 1977, King 1980, Monico, McKenzie 1978, McRorey 1975). These chippers consist of a large chipping flywheel and fed by rollers. They chip primarily sapling type material and are semimobile. They are ground-set in a central forest location and operate in a stationary position. The costs of such chippers are in the range of $90,000 to $150,000. The U. S. Forest Service has recently constructed a portable chipper which uses a track type vehicle for transport and a crane for loading.

To date, few machines which simultaneously fell and chip brush material have been developed. The Pallari Brush Harvester and the Georgia Pacific Biomass Harvester (Monico 1979) use front mounted saws to cut the brush and rollers which feeds the material into a chipper. A third machine is being developed at the University of Maine which uses cutting discs and saws in a header mounted on a crane arm. This machine is similar to the English Bushwacker, however, retains the material. Apparently this device is to be used primarily for cutting hedge brush such as along right-of-ways. The fourth unit is the Brush Combine as developed at Texas Tech University.

Both vertical and horizontal plane knives have been used for shredding. There are a dozen or more manufacturers of such equipment, however, these devices are used to cut brush, shred, and distribute the material on the area cut. Most notable of these are the 150-T Shredder, Muskeg Brush Cutter, Klearway, Hydro-Axe, Double "O" Shredder, Nicholson, Hydro-Mower, Woodsman, Timbermaster, and Shred King. Basic requirement for mechanical brush shredding was reported by Carpenter in 1973. Shredding trials, under the auspices of the project during 1977-78 show horizontal swinging knives as minimum power requirement for cutting brush. This method of shredding, however, would require additional gathering and chipping equipment.

Reports estimate that appeoximately 40% of the tree wood materials harvested by the lumber industry has gone to waste in the form of limb trimmings, topping and saw slabs. This has brought on a new thrust for utilizing the whole-tree concept. The U. S. Forest Service and Department of Energy have been instrumental in developing uses for the whole-tree and investigated equipment for slash chipping. Today's trends are for more waste products being chipped. Much work is currently in progress on the development of systems to use such chips as alternative fuels (Hassan 1980).

CRITERIA, DESIGN AND EXPERIMENTATION

The first mesquite harvester used at Texas Tech University consisted of a front mounted heavy duty shredder with two horizontal flywheels, each having four cutting knives. This unit is an efficient means of cutting the material at the stump, however, requires additional raking, loading, transporting, and chipping. Based upon experiences and review of methods being utilized to harvest similar materials the following criteria was established.

1. If possible, the machine was to be a once over-the-field machine.
2. The whole-tree should be harvested from a standing position.
3. The least possible disturbance of the soil surface and growing grass should be adhered to.
4. The remaining stumps should be uniform in height and cut as low as possible.
5. The machine should accumulate the material and dump in bulk.
6. The field losses of the material should not exceed 50%.
7. The harvesting method should be able to cut trees up to 8 inches in diameter.
8. The harvesting system should permit stump spraying with herbicides.
9. The size of the material should permit easy handling for transporting.
10. The equipment should be as safe as possible to operate.
11. The operating equipment should be sturdy to prevent high down time.
12. The cost of harvesting should be as low as possible and not exceed $10/green ton.

Admittedly, the criteria presented a real challenge in equipment design. The beginning was to study the physical characteristics of the mesquite tree to establish harvesting concepts. The once-over and economic criteria became the key points of consideration. In that no such harvester was available to do the job or come near the criteria established, it was determined that such a machine would need to be developed. It was decided that if a standard power unit or tractor was used, the cost might be reduced. By investigating other combine harvesters it was established that similar handling, hauling, and dumping mechanisms could possibly be used, however, that the necessary header would need to be developed. Also, that if herbicides were to be used to control resprouting a spraying system would also need to be adapted. Cutting mechanisms such as saws, flails, cutting wheels, and swing knives were investigated. Retaining and pickup devices such as rakes, fingers, grappling hooks, etc. were reviewed. Investigations on possible chipping devices such as flywheel chippers, roller chippers, swing knives, helical cylinder knives, and rotor chippers were investigated. The most desirable combination of these devices were then considered. Since no known combination would meet the criteria, a new concept for a header to cut, retain and chip the material was developed. Investigations were made using both vertical and horizontal knives. Field tests showed horizontal rotary knives the more economical for cutting mesquite trees at the base, however, vertical knives driven by a horizontal drum proved the more effective method of shredding and harvesting. The horizontal driven drum with vertical swinging knives was thus selected as a base for a header to be used on the combine.

The development of the header required the construction of an experimental header test stand, with instrumentation, to determine the more effective design features. For example, it was necessary to develop data to determine knife design as related to minimum power requirement, stump cutting ability, cutting speeds, product retainment ability, low maintenance, safety, knife wear, and low field knife change time. Tests were conducted using "T" shape, "L" shape, "U" shape, and "I" shape knives. Data from some 60 tests were used in the final design. Evaluation of the test data resulted in the use of the "U" shape knife, commonly known as a "stirrup shaped" knife. The knife is relatively low in power requirement, simple, and has good chip retention. This knife was redesigned so as to provide sharper corners, and uses a 30° sharpened cutting edge on both front and rear so that the knives can be easily reversed in the field and reduced down-time for sharpening by nearly 50%. Although the tempered knives have had little wear, to date, it is expected the knives will need to be reversed or sharpened on a 7-8 day basis under typical operations.

It was determined, by tests, that conveyance of cut material could be accomplished by the use of flights or paddle chain and pneumatic means. Tests showed a dust problem and expected high power requirement when conveyed pneumatically. Various paddles were investigated and a chain driven especially designed plastic paddle conveyor proved a low power requirement and fair conveyance.

CONSTRUCTION OF A MESQUITE COMBINE

Data from the experimental tests was utilized in the final design of the Mesquite Combine. The header unit was mounted on a standard 135-horsepower P-T-O wheel tractor for mobility and as a source of power. Power is transmitted by a hydraulic system for both raising and lowering the unit, as well as turning the rotating cutting mechanisms. The tractor also transports the material in the field. A rubber tired tractor rather than a track type was selected to meet the criterion of minimum soil surface disturbance and not destroying grass and other ground cover. Maneuverability and higher field speeds are also enhanced by using rubber tired wheels for support and traction devices. In order to prevent flats, which was a problem in the first tests, solid tires are used on the front and air filled steel belted logger type tires are used on the rear.

The cutterhead assembly is mounted on the front of the tractor by means of standard front and hydraulic lift arms. The assembly consists of a structural support frame, cowling, hydraulic motor, drive mechanisms, cutterhead and a push bar to slightly tilt the standing tree forward for cutting.

The cutterhead consists of a 25-inch diameter horizontal cutting cylinder with twenty-six 5-inch stirrup-type knives having a 360 degree swing circle. Under normal operations, a cutting blade speed of 10,000 ft./min. is maintained. Four 1-inch square holding bars are anchored in a 120-degree arc and spaced 4, 2, 1, and 0.5 inches from the knives. The chipped material is received in a 10-inch standard-pitch auger trough and conveyed to the left side of the header. The material is then transferred, by a semi-circular 10-inch chain-paddle conveyor, to an elevated container. The paddles are of a special plastic to withstand the forces encountered in the conveyance system. The elevated container consists of a hydraulic controlled dump basket. The basket is elevated to permit unloading into standard type transporting vehicles or in forming a rick of cut material at ground level. Continuing improvements of the machine are being made following field tests.

MESQUITE COMBINE FIELD TRIALS

Although the proto model mesquite combine has only been used to harvest approximately 60 acres, its operational performance, to date, has exceeded original expectations. It has been operated on varying sloping terrain with handling ease. Except for cutting the grasses growing in the area to the header height, only slight damage was noted. Most of the harvesting performed was in the 1-3 inch height level. Operational speeds in low density mesquite tree populations have exceeded 4 mph, however, median to heavy growth is in the 2 mph range. By changing travel speeds according to the degree of population, the combine was found to be rather even in capacity of tons per hour. Although rates of harvesting reached an anticipated rate of 5 tons/hr., the initial test including transportation time to a dump area for a 12-acre plot, was 3.16 tons per hour. Use of the improved conveyor and hydraulic dump basket has increased the current rate of harvesting to 4.26 tons per hour.

The cutterhead design met design expectations and exceeded some criteria such as material retention. The machine chipped and placed 80.5% to 88.1% of the standing material into the basket. The average of approximately 85% retention far exceeded the 66% hoped for. Lost material remaining on the ground consisted of small leaves, limbs and some horizontal limbs anchored near the ground surface. In most cases the combined areas could be mowed later with standard mowing equipment. The cut material or chips varied in size from leaf material to longer sizes up to 7-inches in length and 3/4-inches in diameter. Approximately 86% of the material was 4-inches or less in length and all material sufficiently small for movement by common conveyors.

When hand separating field dried material into classes and/or sizes by weight the following was noted:

Class A - leaves, beans, finely shredded bark, small stems, and grass	39%
Class B - shredded bark	6%
Class C - small debarked chips and stems	11%
Class D - small chips and stems with bark	20%
Class E - longer stems with bark	4%
Class F - longer debarked stems	20%

The classes were selected mainly upon the physical characteristics which separation for special uses might be accomplished. The percentages will, of necessity, vary with the season and the amount of weeds and grass growing in the harvest area. The dump basket operated as expected and holds 2.25 tons. The material, cut during late summer, was found to have a bulk density of 15.18 lbs. per cu.ft. The moisture content was 47.8% of the wet weight. After four weeks of field drying the bulk density was 9.38 lbs. per cu.ft.

Although trees having 10-inch diameter trunks have been cut, cutting-on-the-go is probably limited to a maximum of 6,7-inch diameter trees. The use of a spring or hydraulic shock absorbing mounting could possibly permit cutting greater trunk diameters.

Problems which were encountered included clogging of the elevator when cutting below design speed of the knives. This causes larger material to enter the elevating system and thus clogging same. Another problem occurred when harvesting in ungrazed areas having tall weeds and grass. The vast amount of airborne material caused the tractor radiator grill to blanket over causing the tractor to run at above normal temperature. The cutter knife speed problem would suggest the need for a tractor having a hydraulic rather than a mechanical forward speed transmission. Secondary radiator grills or a forward blowing radiator fan may also solve the overheating problem.

COST OF HARVESTING WHOLE-TREE MESQUITE

The extent of use of any product depends, to a large degree, upon economic utilization. We are told there are about 78 known uses of mesquite and I would suspect over half of these uses could utilize material in the combined chip form. The mesquite chip is, therefore, assumed to be a usable product, however, it must be competetive economically and show possibilities of profit to entrepreneurs. Costs are, therefore, an important function of utilization.

Since other speakers at this symposium will discuss utilization and total costs, this paper is being confined to the cost of harvesting and delivering a ton of cut material at the harvest site. The following are estimated current costs, without profit, and based upon expected operating procedures.

I. Estimated cost of whole-tree mesquite combine:

1.	Cost of tractor (135 P.T.O. hp diesel, western style, 2 wheel drive)	$42,500
2.	Front end loader arms (standard with cylinders, hoses, and controls)	3,750
3.	Harvesting header assembly (frame, cutting head, shields and basic drives)	26,770
4.	Elevating assembly (chain paddle with drives)	1,680
5.	Dump basket (basket, hydraulic cylinder)	2,800
6.	Hydraulic drive motor (motor, hydraulic lines and controls)	5,500
	Total Cost of Mesquite Combine	$83,000

II. Estimated annual fixed equipment costs:

1.	Depreciation (based on 12,250 hour life and 10% salvage value)	$10,671.43
2.	Interest on investment (based on 15% interest paid in equal installments over life of equipment)	6,847.50
3.	Insurance (1% of value)	830.00
4.	Taxes (1% of value)	830.00
	Total Annual Fixed Equipment Cost	$19,178.93

It should be noted that approximately 80% of the cost of the proto model was supported by donated and salvaged equipment.

III. Estimated daily operating costs:

(Eight (8) hour work day with one (1) hour accredited to moving, maintenance and repair of equipment)

1.	Diesel fuel (7.6 gals./hr. @ $1.10 gal. and actually running 7.25 hrs./day).	$60.61
2.	Oil and grease (10% of fuel cost)	6.06
3.	Repairs and maintenance (45% of new cost divided by life operating days)	21.34
4.	Hydraulic oil (estimated losses)	2.23
5.	Operator (labor, 8 hrs./day @ $5.23)	42.00
	Total Daily Operating Costs	$132.24

IV. Estimated cost of harvesting per ton:

1.	Fixed cost per hour (annual cost of $19,178.93 divided by 1750 annual hrs.)	$10.96
2.	Operating cost per hour (daily cost of $132.24 divided by 7 productive hrs./day)	18.89
3.	Total Cost Per Productive Hour	$29.85
4.	Cost Per Green Ton (4 tons/hr.)	$ 7.46

It should be noted that the green material, harvested during the spring and summer months, contains approximately 47% moisture determined on a wet basis. The harvesting system of $7.46 per green ton was below the original criteria established. This cost is approximately 50% of that encountered by other harvesting operations.

SUMMARY AND CONCLUSIONS

In brief summary the whole-tree and combined system of mesquite removal and harvesting appears to have considerable merit. Although selective hand or other harvesting for special products could be performed before combining, the system is limited to cutting all the material into small pieces. For mesquite control horizontal rotating cutting heads will cut the trunks at lower cost than the combine, however, the material is left on the land. The proto combine header is set forward to permit attachment of a selective stump sprayer to apply herbicides for those who desire to control regrowth of the mesquite.

By using rubber tires on the combine, there is little disturbance of the soil surface and a minimum of damage to grass cover. Stump heights can be cut to within 1-inch of the soil surface and thus permit other operational activity on the area. The combine removes approximately 85% of the cut material on the area. Of that remaining some of the low growing limbs may be stump anchored, however, most of the remaining material lies rather flat on the soil surface.

From a machine standpoint, the combine has out-performed original expectations. The limited hours used does not give positive wear and replacement costs, however, estimates have been made based upon similar equipment use. Some of the minor problems encountered have been eleminated and others are being persued. Undoubtedly continued improvements can be accomplished. The construction of larger units may reduce the cost per ton, however, new problems may also be encountered. The chipping header requires appeoximately 20 horsepower per foot of length.

The chipped material size was selected only for convenience in handling. The final use of the material will apparently determine final material size reduction in the field. Although the holding basket size was somewhat a random selection, the 2 ton size is near the desirable point when considering the power required to haul in the field versus the time lost in dumping. Currently it takes about 20-23 minutes to harvest a 2 ton lot. Allowing for traveling to an unloading site 2 times per hour, the capacity is about 4 tons per hour.

The harvesting cost of $7.46 per green ton makes the mesquite chip very competitive with other woods currently being utilized. Although drying, separation, size reduction and other primary processing will be discussed in another paper this afternoon, apparently a few aspects should be mentioned. If the chips are ambient air field dried for a 3 week period the moisture, under average conditions, will be reduced to 20% or less. This will thus provide a 20% moisture chip for approximately $10.25 per ton. This cost is about one-fourth the going price of cord wood. Although handling and tranportation costs must be added to this cost, it compares very favorably with similar wood material selling for $30 per ton.

As a source of energy, a calorimeter test shows 8504 Btu's per pound of 19% moisture mesquite chips or about 40% the energy of gasoline on a weight basis. One published chart which considers the energy per unit, current costs per unit, and the efficiency of combustion to produce one million Btu's for heating, shows the following comparison: wood chips $1.64, coal $3.56, wood pellets $4.08, natural gas $4.38, fuel oil $8.61, and electricity $15.42.

In conclusion, I am optimistic that this system of harvesting can provide mesquite chips with an economic advantage as a fuel, as a building material, as a feed (by separation), and perhaps other uses on a regional area basis.

MAJOR REFERENCES

Bandyopdhyay, J. K., Carpenter, T. G., Dahl, B. E., and Osborn, J. E. 1974. Systems Approach to Effective Rangeland Brush and Weed Control. Paper presented at 1974 Annual Meeting of Weed Science Society of America - 1974.

Burzlaff, D. F. and W. L. Ulich. 1979. An Improved Field Mesquite Harvester. Noxious Brush and Weed Control Highlight - 1979. Texas Tech University, Vol. 10.

Carpenter, T. G. 1973. Machine Requirements for Brush Shredding. Southwest American Society of Agricultural Engineers paper. Dallas. April 1973.

Chamlee, Tom. 1976. Complete Tree Utilizer - Mark II-A. Nicholson Mfg. Co. Paper II-A. 1976.

Cline, C. R. 1971. Industrial Forester and the Changing Face of Timber Harvesting. Jounral of Forestry, pp. 692-695. 1971.

Durso, D. F. Allen, T. J. and B. J. Ragsdale. 1973. Possibilities for Commercial Utilization of Mesquite. Mesquite Research Monograph 1. November 1973. Texas A&M University.

Echols, R. L. 1971. Laboratory Investigations of Machine Requirements for Mesquite Brush Shredding. Graduate Paper Report. Texas Tech University. October 1971.

Erickson, J. R. 1971. Bark-Chip Segregation; A Key to Whole-Tree Utilization. Forest Prod. J. 21 (9) 111-113.

Fisher, C. E., Hoffman, G. O. and Scifres, C. J. 1973. The Mesquite Problem. Research Monograph 1, Texas A&M University.

Hassan, A. E. and Reeves, R. H. 1980. Compaction of Wood Chips - Physical and Pulping Characteristics. American Society of Agricultural Engineers Transactions, pages 270-274.

Harrison, T. 1977. Operational Tests of Bomford Bushwacker. Bulletin produced by Bomford and Evershed Limited, Eveshan, England, WR115SW.

King, G. W. 1980. Equipment for Wood Chip Quality Control. Williams Pat. Crush and Pulv. Co., Bulletin 766.

Lambert, M. B. 1974. Evaluation of Power Requirements and Blade Design for Slash Cutting Machinery. American Society of Mechanical Engineers, Paper No. 74-1570.

Major References (Cont'd)

Laundrie, J. F. 1958. Pulping of Mesquite, Manzanita and Snowbrush. Forest Prod. Lab. Mimeo 2138, Madison, Wisconsin.

Miller, J. E. 1973. Mesquite Growth and Development Management Economics Control Uses. Texas Agr. Exp. Sta. Research Report.

Monico, J. A. and Soule, H. M. 1979. A Machine to Harvest and Chip Brush Stands. American Society of Agricultural Engineers Paper No. 79-1595.

McKenzie, D. W. and Miller, M. 1978. Field Equipment for Pre-commercial Thinning and Slash Treatment. Forest Service, USDA 7824 1203.

McRorey, R. B. 1975. Equipment Development and Test Program. Forest Service, USDA. 1975 Report.

Olson, J. R. 1980. Champion Forage Harvesting Equipment. Champion Products Int'l Equipment Bulletins.

Schuster, J. L. 1969. Literature on the Mesquite of North America. Special Report #26, Int. Center of Arid and Semi-Arid Lands Studies, Texas Tech University.

Smith, B. 1979. What's New in Total Chip Harvesting. Morbark Indsutries, Inc. Vol. 2, No. 1, pages 2-6.

Ulich, W. L. and Turley, F. R. 1976. Front Tractor Mounted Mesquite Shredder-Sprayer. Noxious Brush and Weed Control Highlights - 1976. Texas Tech University, Vol. 7.

Vannoy, B. M. 1979. Economics of Harvesting and Transporting Mesquite Chips. Agricultural Engineering Department Report, Texas Tech University. August 1979.

Vidrine, C. G. and Robbins, W. D. 1977. Forestry Mechanization at Louisiana Tech University. Southwest Region American Society of Agricultural Engineers Paper.

MESQUITE AS A BIOMASS RESIDUE[1,3]

Harry W. Parker[2]

Options for utilization of harvested mesquite wood are reviewed including wood products, fuel, and animal rations. It is difficult for mesquite to compete with commercial forests due to the small size of mesquite trees and the low yield per acre. The combined gains from increased ranch-land productivity and the value of mesquite as a fuel or animal rations may make its harvesting attractive in some cases.

INTRODUCTION

In the preceding papers, Drs. Dahl and Ulich have described mesquite as a range-land plant and discussed techniques for harvesting it. If harvested mesquite had obvious commercial value in excess of its harvesting costs much of the over 50 million acres of mesquite infested land in Texas would have been harvested already, and we would not be attending this symposium. Unfortunately, mesquite is not a current cash crop, but effective utilization of harvested mesquite has the potential of contributing to the profitability of ranches. For this reason the many opportunities for the utilization of harvested mesquite must be analyzed, and the most desirable ones implemented when economically attractive.

UTILIZATION OF HARVESTED MESQUITE

Figure 1 lists the possible uses for harvested mesquite. For each of these uses there are established commercial alternatives to mesquite. Mesquite must prove itself superior to these alternatives or less costly to displace these existing materials.

Wood Products

It is obvious to consider using mesquite as wood for furniture and construction purposes. Unfortunately, few trees are of commercial size and

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many of those have serious defects. The resulting wood is reported to be hard, very beautiful, but brittle (Marshall 1945). A paper to be given this afternoon will observe that commercial cabinet shops found kiln dried mesquite wood as easy to work as many commercial woods (Larson & Sodjoudee 1982). Direct use of trees for wood is a selective process, leaving much of the mesquite on the ranch land. Prior to harvesting the mesquite to increase the productivity of ranch lands, it might be a attractive to selectively remove larger trees for wood. This decision would be dependent on the size and condition of available mesquite trees, plus the initiative of individuals to market mesquite wood or items made from it. For most mesquite infested land, selective removal of wood will not be financially attractive.

Even though wood pulp for paper products can be produced from mesquite wood, (Laundrie 1950) the technical feasibility does not necessarily make paper production from mesquite practical. Two factors are responsible for not making paper from mesquite. First, the harvested mesquite contains bark which can not be conveniently separated from the wood as in the case of paper mills processing conventional logs. Second, the relatively low yield of mesquite per acre makes transportation of mesquite to a paper mill of sufficient size to be competitive too costly.

Fiberboard or chipboard could potentially be made from harvested mesquite, but it has not been marketed commercially. Mesquite based chipboards would have to compete in existing markets. In 1975 Dr. Peter Koch consulted with the Texas Tech Mesquite Utilization committee and stated that any conventional forest products which might be made from Texas mesquite could be produced more economically from cull trees within the existing forest products industry (Koch 1975). This statement by a recognized authority on utilization of marginal forest resources should be given serious consideration before investing significant amounts of money and time for the conversion of mesquite to conventional forest products such as wood, paper, or chipboard.

Fuel and Chemical Feedstocks

The utilization of biomass for fuel is expanding since in some circumstances it is less costly than coal. Biomass offers the advantage over coal by being low in sulfur and not contributing to "greenhouse effect" caused by carbon dioxide additions to the atmosphere. Mesquite can potentially contribute to this source of energy and is the largest potential source of agricultural biomass residues in Texas, 680 million green tons (Wiley 1971). The total amount of this mesquite residue is small compared to the reserves of petroleum, natural gas and lignite in Texas. On a BTU content basis mesquite is equivalent to 15% of the producible petroleum reserves within Texas. Harvested mesquite will not solve the energy needs of Texas, but the energy requirements of Texas can potentially provide a productive use for harvested mesquite.

The most direct potential use of harvested mesquite it to fuel large commercial boilers. In the past, use of biomass mass for boiler fuel was limited to the forest products industry and sugarcane industry, where the fuel was already available at the plant site. More recently, other

FIGURE 1

USES FOR HARVESTED MESQUITE

I. WOOD PRODUCTS

Wood - Conventional or speciality products

Paper products

Fiberboard or chip board

II. ENERGY AND CHEMICAL FEEDSTOCKS

Boiler fuel - utility, industrial, enhanced oil recovery

Transportation fuels - ethyl alcohol, methyl alcohol, and other synfuels

Chemical feedstocks - ammonia, methyl alcohol, acetic acid, etc.

Residential fuels - firewood, fabricated firewood, chips for barbecueing and charcoal

Agricultural energy needs - direct combustion for drying agricultural products or steam for grain processing
- producer gas generators to fuel tractors, trucks, and electric generating plants

III. ANIMAL FEEDS

Maintenance rations

Growing and finishing rations

Fermentation processes - ethyl alcohol, yeast, etc.

IV. Miscellaneous uses

Tannin

Mesquite Gum

Food

Chemical specialities

firms have started installing wood-fired boilers (Berry 1980). The largest potential use for mesquite fired boilers is in the production of electricity. Here, the choice must be made between firing mixtures of mesquite and coal in very large boilers, or employing much smaller boilers which use biomass exclusively. The economics of scale greatly favor the first choice where possible. In this case, mesquite or other biomass residues must be made available to utility companies on a long term basis at a price sufficiently below that for coal to justify the additional equipment needed to feed the mesquite to the boilers. The same concept can be applied to other sources of biomass such a municipal solid waste, agricultural residues etc. The only major attempts at simultaneously burning coal and biomass have been in using municipal solid waste. The technique has not been received widespread acceptance. If mesquite harvested from ranch lands were to be the exclusive fuel for generation of electricity the generating facilities would be quite small compared to the sizes constructed by large utilities--10 to 50 megawatts contrasted to 300-1000 megawatts. Small facilities are necessary to minimize transportation costs for the harvested mesquite, but require more operators and approximately 60% greater investment per kilowatt of generating capacity (Fraas 1982). The fuel use act has provided the opportunity for individuals or private companies to produce electricity and sell to the utility companies at favorable terms, so the opportunity exists for burning harvested mesquite for the production of electricity. A detailed site specific analysis would have to be made to determine if electricity can be generated in relative small facilities and sold for a adequate financial return on the required investment. This afternoon Dr. Smith will present cost estimates for a $6MW_e$ generating plant which would produce electricity for about 5¢/hw-hr by burning mesquite (Smith 1982).

Industrial plants require steam in widely varying amounts. For some low quantity of steam consumption the inconvenience and additional investment required to burn a biomass residue such as mesquite is not justified. Natural gas, LPG, or fuel oil will continue to fuel small boilers and steam generators. The upper limit on using biomass as a boiler fuel is limited by transportation costs for mesquite. For continued usage, estimates would have to be made regarding the rate of mesquite regrowth.

The investment required for a wood fired boiler is approximately 200% more than that of a gas or oil fired boiler. In addition investments must be made in facilities to harvest, transport and store mesquite. These additional investments must be made financially attractive by the difference in cost to the industrial user between mesquite and either oil or gas. In addition, mesquite must be a available for a lower cost than coal, lignite, or other biomass residues. For some biomass residues the cost of collecting need not be charged to the cost of the fuel since it must be collected whether it is burned for fuel or discarded. Gin trash, bagasse, and municipal solid waste are examples of potential biomass fuels which must be collected whether they are utilized or not. In fact, avoidance of disposal costs can subsidize the cost of using the residue as a fuel. For example, trucks transporting municipal solid waste are frequently charged a fee for dumping their loads at the incinerator. It is not essential that mesquite be harvested, so all or a portion of its collection cost must be allocated to the price of mesquite sold to the industrial user. The problem of allocating costs will be discussed subsequently in this paper. Again site specific analysis must be made for each case to determine if harvested mesquite is a financially attractive industrial boiler fuel.

Heavy oil and tar are frequently produced by injection of steam. In the US, 77% of oil produced by enhanced oil recovery is produced by injection of steam (Oil and Gas Journal 1982). This same reference cites 4 steam injection projects in Texas. In circumstances where mesquite covers the land from which heavy oil is being produced there is a unique opportunity to utilize the mesquite as fuel to generate the steam used to recover the oil. The opportunities for utilizing harvested mesquite for oil recovery will be discussed in greater detail in a paper given this afternoon (Parker 1982a).

Transportation Fuels

Many of our nation's energy concerns focus on transportation fuels since these are almost entirely produced from petroleum. Changes in the international politics could greatly restrict oil imports, create major national security problems, and domestic inconveniences such as fuel allocation and gas lines. This problem is acknowledged by most persons, but self-interests of the groups' concern and politics has precluded establishment of an effective energy policy. Harvested mesquite can be converted into transportation fuels by two routes. One option produces ethanol by fermentation of chemically processed mesquite. The chemical processing of wood such as mesquite for subsequent fermentation into ethanol is rather costly and is not expected to be competitive with other transportation fuels, even ethanol fermented from grain. The second option employes thermal processing of mesquite. The least complex process is to pyrolyze the mesquite converting it to charcoal, gas, and oil. The oil is of a very low quality oil which must be severely refined to convert it to consumer fuels. Beginning in 1968, personnel at Georgia Tech developed and tested a mobile biomass pyrolysis unit which might be suitable for mesquite (Bowen et.al. 1978). This unit has not found commercial acceptance. The other option for thermal processing mesquite into transportation fuels converts the mesquite to synthesis gas by gasification. The synthesis gas, a mixture of hydrogen and carbon monoxide, can then be converted to methyl alcohol or by Fischer-Tropsch synthesis into gasoline and diesel fuel. Synthesis gas can also be converted into a wide variety of chemicals. The potential chemical of most interest for agricultural purposes is ammonia. For over 10 years Texas Tech personnel have investigated the gasification of biomass for conversion to ammonia (Beck & Wang 1980).

Gasification and the subsequent synthesis of the desired products are sophisticated processes conducted at high pressures and temperatures. For this reason, these processes are only practical in very large operations. The lower limit on practical plant size for production of transportation fuels is on the order of 25,000 tons per day of coal. It would not be possible to gather sufficient mesquite for such a facility. The economies of scale so heavily favor very large plants that it may be impossible to utilize biomass for production of chemicals or transportation fuels. The better tactic may be to utilize coal for production of these materials when natural gas or petroleum are no longer available.

Biomass residues can still be effectively utilized for boiler fuels as discussed previously (Parker & Whetstone 1974).

Residential Fuels

Mesquite has a long history of being employed for firewood and that opportunity continues. Due to the small size and bushy character of most mesquite trees, considerably more labor is required to gather it than from many other species of trees. The resulting firewood is rather crooked and irregular in size. For this reason, firewood trucked from some relatively distant location is sold locally more often than native mesquite wood. Removal of mesquite for firewood frequently leaves the smaller trees so it is not an effective means of clearing ranchland of mesquite. Harvested mesquite wood can be extruded into logs of uniform size, but the cost of doing so limits their market. They must compete with similar logs made from tumbleweeds, gin trash, and other woody residues. Marketing mesquite wood chips for barbecue may be profitable for a few individuals, but the potential market is too small to clear mesquite from a significant amount of Texas ranchland.

Charcoal can be produced from almost any woody residue by heating in the absence of air, frequently called pyrolysis. Its domestic market is a limited one as a luxury fuel. If mesquite were utilized for charcoal production it would have to displace existing producers from the market. This displacement would be a difficult task since they frequently minimize harvesting costs by use of the residues from other lumbering operations and have already made their investment in processing facilities. Activated charcoal is a speciality market which would also be difficult to enter.

Agricultural Energy Needs

It would seem reasonable to use mesquite to furnish the energy needs for farms and ranches. Proven technologies are available to accomplish this purpose and could make the ranch with abundant mesquite resources independent of external energy supplies. The rather high investments required to utilize these technologies plus their labor intensiveness has precluded widespread usage of mesquite to supply ranch energy requirements. A recent study has suggested that the agribusiness can best insure its energy needs by participation in an effective national policy instead of trying to become independent of external energy sources (Parker & Holmes 1979). As a matter of completeness, the options for using mesquite to energize ranches will be briefly described.

Steam needed for feed processing and energy needed for drying agricultural products can be produced directly by combustion of mesquite. Sufficiently small boilers and burners may not be commercially available for this purpose, since the market does not presently exist, but they could be designed and built if needed. To power trucks and tractors, fuel is required for internal combustion engines. Mesquite wood can be converted to a gaseous fuel suitable for these engines by means of a small producer gas generator. In a producer gas generator the engine draws air through a bed of burning wood or charcoal particles. The gases leaving the burning materials contains enough hydrogen and carbon monoxide to fuel the engine. Most civilian transportation in Europe during

World War II was fueled by wood and charcoal using these producer gas generators. These devises are inconvenient to operate, increase requirements for engine maintenance, and reduce the available power by approximately 40%. For these reasons, producer gas generators have not been commonly used for transportation purposes except in times of national emergencies. For stationary engines such as employed to generate electricity or pump irrigation water, these disadvantages are not as severe, but still there has been no commercial domestic usage of producer gas generators to fuel internal combustion engines in recent times. Agricultural engineers at the University of California have led the renewed investigation of producer gas generators (Goss 1978). Their generators require granular materials such as corn cobs. Fibrous harvested mesquite could not be used unless it were pelletized, an investment intensive operation which would increase the cost of mesquite wood supplied to the gasifier by several dollars per ton. A small gasifier for fibrous materials such as harvested mesquite or cotton gin trash has not been demonstrated, and its development would be a challenging mechanical task. Since existing gasifiers for granular materials are not being employed for domestic agricultural purposes, there is little incentive to develop a special gasifier for fibrous biomass residues such as harvested mesquite.

Animal Feeds

The use of harvested mesquite for animal rations has a particular attraction in that the mesquite harvested on a ranch might be fed to cattle on that same ranch. This choice would minimize transportation costs and simplify business arrangements since only ranchers would be involved. Even if the process used to convert the mesquite into animal rations were so elaborate that a central processing facility were needed, landowners are accustom to cooperative financing and operation of similar facilities such as elevators and gins.

Texas Tech has expended considerable research effort developing methods of converting mesquite into animal rations, since that would be a convenient use of mesquite for ranch operators. This afternoon, six papers will be presented reporting current work. Research regarding another technique was published previously (Parker et.al. 1979). Laboratory scale development of treatment methods to convert mesquite into animal rations can be accomplished rather quickly for modest expenditures. Feeding tests of the treated mesquite are expensive and time consuming since a statistically significant number of animals must be fed over a long period of time. In additional to the expense of animals and their maintenance, large quantities of processed mesquite must be prepared for the feeding test. Preparation of processed mesquite for feeding tests requires pilot plants capable of processing several pounds, or preferably several hundred pounds in one batch. Such a pilot plant frequently will be made of stainless steel, operate a elevated pressure, and require sophisticated instrumentation. Design and operation of these pilot plants require considerable funding and effort by experienced chemical engineers. Texas Tech has built and operated one mesquite processing pilot plant.

Treated mesquite employed in animal rations must be nutritionally and economically competitive with grain or hay. This fact places an upper bound on the expenditures which can be made per ton of mesquite treated. Economic constraints on the treatment of mesquite for animal rations are the subject of a specific paper this afternoon (Tock 1982).

Miscellaneous Uses

Tannin which is useful in tanning leather and treatment of oil field drilling muds can be extracted from harvested mesquite, but the yield is rather low, about 10 %, and rather impure. If mesquite wood were being processed for another purpose such as animal rations, tannin might be considered as a by-product (Marshall 1953).

Mesquite gum has been harvested for making gum drop candy and home remedies. Harvesting the gum is a labor intensive process of tapping the trees and subsequently returning to gather the gum. Early in the century it was harvested commercially (Marshall 1947). Today there is no commercial marketing of domestic mesquite gum and it would be difficult for it to compete with similar gums produced by less labor intensive processes or imported gums.

Research workers in the Chemistry Department at Texas Tech have isolated complex polyphenolic compound in the mesquite wood and assigned it the trivial name mesqutitol. About 2.5% of mesquitol is present in mesquite heartwood. Its discovery and potential uses will be discussed this afternoon (Bartsh et.al. 1982).

Mesquite beans have been and still are a food source for indigenous populations in semiarid climates. Their nutritional value has been examined with modern techniques and the results are reported in three papers this afternoon.

The combined potential of mesquite to facilitate nitrogen fixation, produce food for animals and humans, supply wood, and provide cover for wildlife represent positive aspects of mesquite trees. These desirable features of mesquite trees will be discussed in papers this afternoon. Determining when it is better to cultivate, or at least utilize existing mesquite stands, instead attempting to eradicate mesquite is a decision to be made by those persons responsible for a particular parcel of land. Continuing work regarding mesquite utilization will gather new facts to facilitate this decision. Our mission at Texas Tech has been primarily concerned its eradication and opportunities to utilize the mesquite harvested during its removal.

MESQUITE UTILIZATION AS AN INCENTIVE FOR ITS REMOVAL

Mesquite utilization can partially offsetting the cost of its harvesting to accomplish water conservation and to renew cattle carrying capacity. This concept is illustrated by the following equation:

Annual Loss per Acre Due To Mesquite	GREATER THAN	Annualized Cost of Removing Mesquite Per Acre	MINUS	Sale of Harvested Mesquite Per Acre

Each term in this equation must be carefully determined in order to make a rational decision regarding the removal of mesquite. Dr. Dahl has provided you with information regarding the reduction of cattle carrying capacity due to the presence of mesquite and consumption of water by mesquite. The ranch operator's perception of the market conditions for cattle and data regarding particular location such as density of mesquite growth and average rainfall can convert this information into an estimated loss per year due to the presence of mesquite.

Dr. Ulich has discussed the cost of harvesting mesquite. Considerable data are available from other sources regarding herbicides and other methods for destroying mesquite. The immediate cost of mesquite control must be spread over the length of time the treatment is effective based on interest rates and accounting methods employed by the ranch operator.

I have discussed the opportunities for the use of harvested mesquite and indicated the constraints which limit the potential sales price of harvested mesquite. It is not necessary that the value of mesquite exceed the cost of harvesting in this equation, only the cost of harvesting minus the income from the sale of mesquite must be less than the losses due to the presence of mesquite. To justify harvesting mesquite instead of destroying it, the value of the harvested mesquite must exceed additional cost for harvesting compared to alternatives such herbicides and controlled rangeland burning.

A considerable investment must be made to harvest and utilize the mesquite. The direct risk of this investment money is that the utilization process will fail or the market for the product will fail. This direct risk can be minimized by careful research, engineering and selection of markets. The indirect risk to this investment is caused by possible changes in other terms of the equation. For example, if market demand for beef decreased and adversely affected the potential income per acre of ranchland the short-term incentive to remove mesquite would be diminished. If the ideal herbicide was developed--effective, selective, and economical--this might be less costly than harvesting and utilizing the mesquite. In either of these cases harvesting of mesquite would not be the most economical choice, and the investment made in a mesquite utilization process might be in jeopardy.

In many cases, mesquite utilization must be accomplished in a central processing plant. Developing the legal and financial arrangements for the construction of this plant will require considerable business and organizational skills. If there is not an obvious and significant profit to be gained by construction of the mesquite processing facility entrepreneurs will not initiate its construction. It may be necessary for ranch owners assisted by universities, and federal and state agencies to take the lead in detailed planning and financing of the mesquite processing facility.

CONCLUSIONS

The opportunities for utilization of mesquite are quite varied including animal rations, wood products, and fuel. Unfortunately, none of these uses for mesquite are sufficiently attractive to convert mesquite into a cash crop. The increase in ranch-land productivity due to removal of mesquite combined with utilization of the harvested mesquite can potentially be of benefit to ranch operators. Careful financial analysis is required to select the preferred techniques for mesquite management.

REFERENCES

Bartsch, R.A., S. Chen, and I.S. Pendergrass. 1982. Isolation of non-carbonhydrate organic chemicals from mesquite. In (Parker 1982).

Beck, S.R., M.J. Wang. 1980. Wood gasification in a fluidized bed. I&EC Process Design & Development, Vol. 19, pp. 312-317.

Berry, R.L. 1980(Ap.21). An ancient fuel provides energy for modern times. Chemical Engineering. pp. 73-75.

Bowen, M.D., E.D. Smyly, J.A. Knight, and K.R. Purdy. 1978. A vertical-bed pyrolysis system. ACS Symposium Series No. 76. American Chemical Society.

Fraas, A.P. 1982. Engineering evaluation of energy systems. p. 253. McGraw Hill, New York.

Goss, J.R. 1978. Food, forest waste = low btu fuel. Agricultural Engineering, Vol.59, No. 1, pp.30-37.

Koch, P. 1975. Personal communication to Texas Tech Mesquite Utilization committee, July 14, 1975.

Larson, R.E. and M. Sodjoudee. 1982. Mesquite utilization potential: from the stump to the finished product. In (Parker 1982).

Laundrie, J.F. 1950. Pulping of mesquite, manzanita, and snowbrush. Forest Products Laboratory Report No. 2130 as reported in (Soltes 1977).

Marshall, E.D. 1953. The outlook for the utilization of mesquite. Journal of the Forest Products Research Society. Vol 5. No. 5. pp. 68-71.

Marshall, E.D. 1945. Utilization of mesquite. Texas Forest Product's Note No. 3. Texas Forest Service. Texas A & M University.

Oil & Gas Journal. 1982.(Ap. 21) Annual production report. pp. 139-159.

Parker, H.W. and G.A. Whetstone. 1974. Fuels and petrochemical feed-stocks from agricultural wastes. Chemical Engineering Symposium Series No. 142. American Institute of Chemical Engineers.

Parker, H.W., R.C. Albin, T.E. Vernor, and D.W. Fahle. 1979. Thermochemical modification of mesquite for ruminant rations. American Institute of Chemical Engineers Symposium Series No. 184, pp 1-6.

Parker, H.W. and L.H. Holmes. 1979. Alternative energy sources for agricultural applications including gasification of fibrous residues. Rept.No. EDF-018. Texas Energy and Natural Resources Council, Austin, Texas.

Parker, H.W.(ed). 1982. Mesquite utilization-1982. College of Agrilcultural Sciences, Texas Tech University, Lubbock, Texas.

Parker, H.W. 1982a. Use of mesquite to fuel oil-field steam generators for enhanced oil recovery. In (Parker 1982).

Smith, M.L. 1982. Economics of power generating systems with mesquite. In (Parker 1982).

Soltes, E.J.(ed). 1977. Proceedings mesquite utilization conference. Forest Science Research Note No. 4. Texas A & M University. College Station, Texas.

Tock, R.W. 1982. Some economic considerations on the use of mesquite in ruminant rations. In (Parker, 1982).

CURRENT AND POTENTIAL UTILIZATION OF MESQUITE IN SELECTED DEVELOPING COUNTRIES

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The typescript for this paper was not available at press time. Copies will be provided participants at the symposium.

THE USE OF OZONE AND WATER IN THE HYDROLYSIS OF MESQUITE[1]

Kenneth W. Cox[2] and Richard Wm. Tock

Abstract[3] - Selected methods which use a combination of ozone and water for hydrolysis of mesquite biomass were investigated. These methodologies included gas phase ozonalysis, liquid phase ozonalysis in an acetic acid medium, with H_2SO_4, NaOH, and warm water pretreatments. The desired product was a glucose solution. Glucose levels were monitored with HPLC. A combination of gas phase treatment followed by liquid phase ozonalysis produced the best results. However, mesquite cannot compete with other woody biomass resources as a source of wood sugars.

INTRODUCTION

The purpose of this paper is to investigate the feasibility of using an ozone-oxygen mixture to assist in the hydrolysis of wet mesquite biomass. The product sought is a fermentable solution of glucose. The utility of ozone is expected to be twofold, since it has the potential to both break down the lignin structure through chemical reaction and at the same time enhance scission of the cellulose structure into D-glucose.

Recent mesquite studies have concentrated on modifying and upgrading shredded mesquite for use as a ruminant feed and roughage source (Vernor, 1977; Chang, 1981). Several methods of chemical pretreatment, including SO_2, caustic, acid, H_2O_2, ethanol, and ozone treatments have been investigated. The resulting mashes produced by such chemical treatments were tested and compared through in vitro digestibility experiments using rumen fluids from cattle. Investigators at Texas Tech University began some of these experiments in the early 1970's.

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[3]This research was supported in part by line item funds provided by the Texas Legislature entitled "Research in Mesquite Utilization".

Since ozone studies on pretreating mesquite biomass to prepare it as a ruminant roughage had shown promise in destroying the ligno-cellulose structure, it seemed reasonable to investigate the hydrolysis action of water and ozone on mesquite. The goal would be to reduce the cellulose fractions to their constituent sugars which could then be converted to fuel grade alcohol. Such processing with other chemical treatments has been demonstrated for woody materials in the past. The question was whether it could be accomplished with mesquite and if so, could the pre-degradation with ozone and water assist the conversion process.

CHEMISTRY AND STRUCTURE OF WOOD

Woods are usually divided into two major classes: hardwoods and softwoods. The woody materials in each class differ in density, structure, and composition. Mesquite is designated as a hardwood and its basic constituents can be identified as lignin, cellulose, and hemicellulose.

Lignin is the crusty part of mesquite and all woody materials. Lignins are natural polymeric products that consist of three primary precursors: *trans*-coniferyl, *trans*-sinapyl, and *trans*-*p*-coumaryl alcohols. These products can be divided into three classes: softwood, hardwood, and grass. Softwood is formed principally from coniferyl alcohol. Hardwood lignin is formed primarily from coniferyl and sinapyl alcohols and grass is formed from all three precursors (Allen, 1980). Softwoods generally have a higher lignin content than hardwoods (Table 1). The lignin fractions in wood range from 20-40% of the total mass. It is typically close to 25% of the mesquite weight.

Table 1. Lignin Comparisons for Hardwoods and Softwoods (Allen, 1980).

Lignin Sources	Precursor(s)	Lignin Content % by weight
Softwoods	Coniferyl Alcohol	24-33
Hardwood	Coniferyl and Sinapyl Alcohol	16-24

Wood lignins are also frequently, inextricably bound to the cellulose. This structure of lignin and cellulose makes wood difficult to degrade with either caustic or common acids. Because of their inert characteristics, lignins present a major problem in the hydrolysis of mesquite. Not only does the lignin matrix itself have to be broken down, but its bonds with the cellulose must also be broken. However, degraded to molecular weights below 500, most portions of the lignin may be extracted with basic solutions (Whistler, 1971).

With ozone, degradation of lignin is accomplished by oxidation of the aldehyde, ketone, or alcohol groups. After the ring structures have been opened, large portions of the lignin fractions can be extracted (Kratzl, 1976).

Lignins can be used as an additive for the manufacture of vanillin, hydrated phenols, resins, tanning agents, permutoids, adhesives, and as an additive to wood for strength. These aromatic compounds also have a high fuel value and can be used as a Btu source for energy consuming processes (Brauns, 1960).

Another troublesome portion of mesquite is the hemicellulose. This fraction of wood consists of condensation polymers of several saccaride units. Included in the building units are D-mannose, D-galactose, D-xylose and L-arabinose. Mesquite has been found to contain large portions of xylose in its hemicellulose fraction (Sands, 1935). Hemicellulose components make up 20-30% of the dry mesquite weight.

It has been found that the hemicellulose is actually an inhibitor to the ozone degradation process as well as to any subsequent fermentations (Goring, 1981). Because the presence of hemicellulose hinders both lignin degradation and fermentation it is necessary to remove it. Major portions of the hemicellulose fractions can usually be extracted with strong solutions of NaOH or weak solutions of H_2SO_4. Solutions of 10% w/o NaOH are commonly used in wood pulping processes to remove hemicellulose and to swell the wood.

In tests with birch wood, pentose extraction by NaOH was studied extensively. It was found that fine grinding of the wood aids in extraction. The optimum concentration of NaOH was found to be 8-12% NaOH. The temperature that produced the highest pentose extraction was 80°C. It also appeared that the amount of pentose extracted did not increase after four hours.

The largest fraction of mesquite contains α-cellulose. Upon hydrolysis, cellulose chemically cleaves into D-glucose. Formulas for various glucose forms are in Appendix A. Six-carbon sugars represent a major potential value of mesquite at the present time. Glucose has value as a nutrient, or it can be used as a feedstock for the production of fuel grade alcohol by fermentation. However, cellulose, in its polysaccaride form, is not soluble in water. In acidic conditions, cellulose hydrolyzes into glucose monomers which are soluble in water. The glucose solution can then be fermented into ethanol. Because of the normally strong bonding between the lignin and cellulose, however, complete hydrolysis of cellulose is difficult to achieve.

Processes which use acid hydrolysis, enzyme hydrolysis, or combinations of both to obtain glucose have and are being investigated. Small scale plants have been built using varying concentrations of sulfuric and hydrofloric acids (Berry, 1981).

REACTIONS WITH OXYGEN-OZONE AND MOIST WOOD BIOMASSES

Ozone is a very powerful oxidizing agent. When contacted with wood, ozone can oxidize the lignin, hemicellulose, or the cellulose as well as the bonds between the different fractions (Kiryushima, 1971).

The reaction seems to take place at random, attacking any aldehyde, keto, or alcohol group on contact. After ozone was contacted with mesquite, the lignin was extracted and analyzed. The molecular weights of the soluble fractions were spread over a wide range (Kiryushima, 1971). Moore (1976) noted that the xylan fraction of wood remained relatively intact upon ozonalysis.

Lantican (1965) investigated the treatment of red cedar with ozone. The advantages and disadvantages of vapor phase treatment were examined. In the gas phase, the penetration of ozone into the wood is faster and more uniform due to the lack of surface effects. Moisture is needed to swell the wood and open the cellular structure. Lantican used 11-20% moisture contact in his vapor phase experiments and found extensive degradation of the cell walls. Research also indicated that a thin water film covering the cell wall resulted in more efficient absorption of ozone gas (Schuerch, 1963).

Chang (1981) developed a basic model for the reaction of ozone with wood. The gas or liquid reactant must first reach the film surface of the wood. This can easily be accomplished by convection. The second barrier is the stagnant film outside the wood. This step is slow and diffusion controlled. The final barrier is the solid wood itself. The ozone must diffuse some distance before it can react with hydrocarbon oxygen groups. Overall, the reaction is diffusion controlled. If there is no film, the wood does not swell and the third phase becomes even more of a limiting resistance. If too much of a water film is present, the wood may swell too much, and both the second and third resistances may become more pronounced.

Chang (1981) conducted several experiments concerning mesquite treatments with ozone. His purpose was to increase the *in vitro* digestibility (IVDMD) of mesquite. His investigations included water-slurry contacting, gas contacting of moist mesquite in fixed beds, and methods where the feed gas pressure was varied. Although all methods increased the IVDMD to some extent, he concluded that mesquite contacted with 60% water by weight in a fixed bed reactor gave the best results. The optimum reaction time for his system was found to be two hours. The initial concentration of ozone in these experiments was 50 ppm. A significant temperature rise during initial contacting suggested that the reaction was exothermic. Furthermore, lower temperatures favored increased reaction rates. This was attributed in part to the increased stability of ozone at the lower temperatures.

In recent studies (Mbachu, 1981), delignification of woody structures was attempted with ozone in an acetic acid medium. The lignin was stirred in a 45% acetic acid solution while ozone was bubbled through the reacting mass. This choice was made because earlier findings had indicated that: (1) ozonation of lignin proceeds much more quickly in this medium than in water alone, (2) ozone molecules are relatively more stable in this medium, (3) the lignin fractions as well as the wood are insoluble and unaffected by aqueous acetic acid solution, and (4) ozonization of cellulose in acetic acid solutions seems to protect the cellulose chains from cleavage. The ozonolysis of spruce periodate and cuaxam lignins and protolignin in spruce wood was studied in 45% acetic acid at room temperature. Stirring affected the rate of reaction, and degradation followed first order kinetics. Spruce wood meal was contacted with ozone in 45% acetic acid at room temperature and lignin, hemicellulose and cellulose fractions were measured as a function of time of ozonalysis. The results indicate that though the attack on wood by ozone is not selective in this medium, lignin degraded almost four times faster than the carbohydrates. These results indicate that by using acetic acid as a medium, it may be possible to save much of the cellulose portion (Table 1).

From this survey it appears that ozone randomly attacks any oxygen group on contact. A gas phase reaction at low temperatures seems to favor ozonolysis although a 45% acetic acid acid liquid phase medium can be used to have ozone preferentially degrade the lignin portion of wood.

EXPERIMENTAL

Since Chang has previously found optimum conditions for mesquite lignin degradation with ozone in the gas phase, efforts in this work were concentrated on pretreatment and post-treatment effects on the recovery of glucose from wood biomass. Therefore, ozone, NaOH, water, and H_2SO_4 treatments were investigated for lignin and hemicellulose removal along with acid treatments for completing cellulose hydrolysis. The gas phase treatments were the same through all samples. All samples were from 24-40 mesh Honey Mesquite (harvested during the summer). The relative lignin, cellulose, and hemicellulose compositions were 20%, 37%, 27%, respectively. The remaining 16% consisted of crude protein, ash, and nitrogen (Chang, 1981).

Gas Phase Reaction

The reaction vessel used was a U-shaped gas washing bottle with a fritted glass bottom to support the mesquite biomass and provide a distribution plate for the ozone. A Welsback 310 ozone generator was used for ozone supply (Fig. 1). Chang had used the same generator at the same power and flow rate setting and determined the ozone concentration to be 50 ppm. The ozone concentrations were assumed to be 50 ppm in this work also. This stream was bubbled through water at 0°C to saturate the gas with water

Table 1. α-Cellulose, Hemicellulose and Lignin Content of Ozone Pulped Samples (Spruce Wood Meal)

Time of Ozone-Treatment (min)	Klason Lignin (% of pulp)	α-Cellulose (% of original sample)	Hemicelluloses (% of original sample)
0	27.6	42.3	20.5
5	24.6	41.5	19.3
10	21.6	40.9	19.7
15	20.4	41.6	18.3
20	18.6	40.4	17.4
40	18.2	38.0	16.7
60	13.3	37.9	16.1
80	10.3	36.5	10.3

(Mbachu, Manley, 1981)

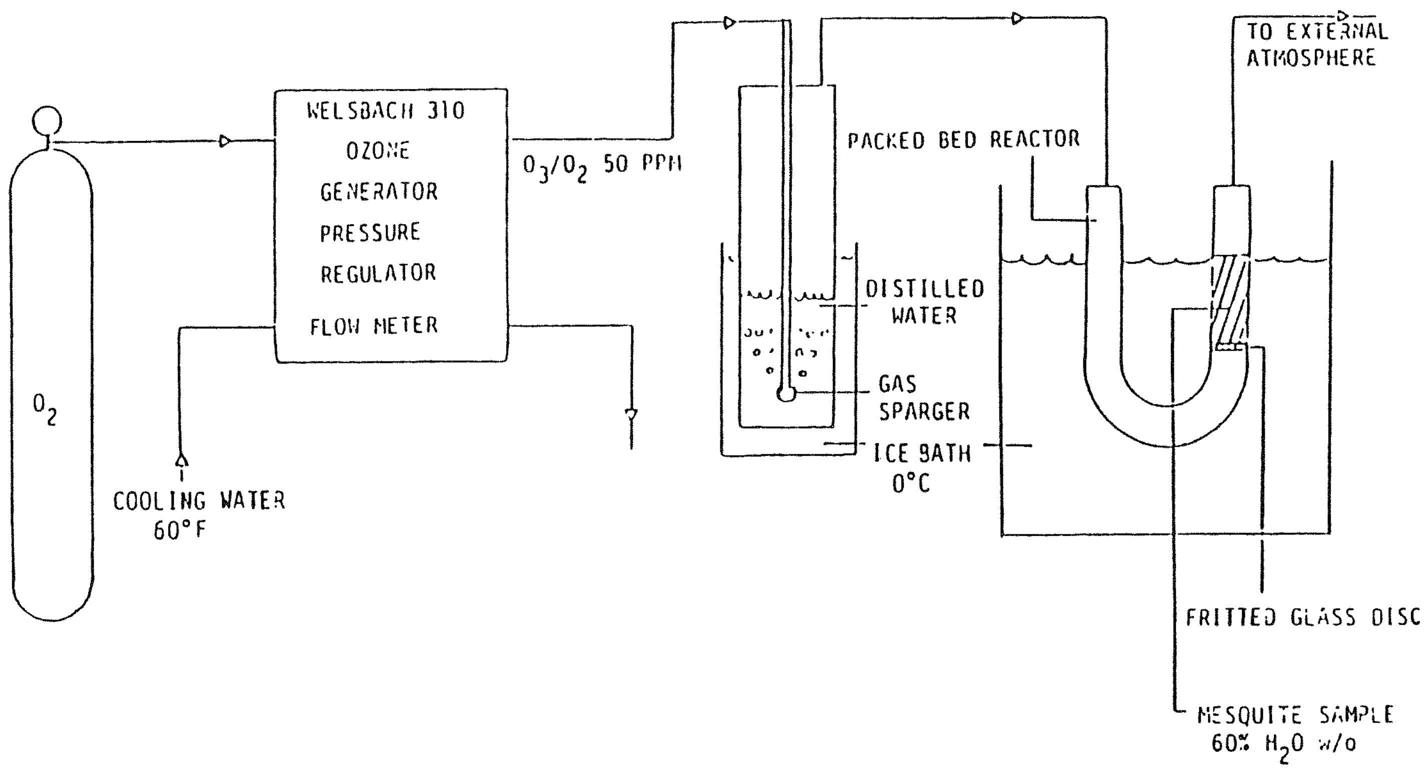


Figure 1. Apparatus For Gas Phase Ozonalysis
Pressure: 15 psig
Flow Rate: 2 slpm at 70°F, 8 psig

vapor. The gas was then sent into the reaction vessel which also was submerged in an ice bath. The low temperatures produced by the ice baths were necessary because the reaction is exothermic and ozone is more stable at low temperatures. The resulting effluent gas was released through a vent to the atmosphere outside the room.

Test samples consisted of 10 to 20 grams of oven-dried (1 week at 45°C) wood with 60% water by weight to increase swelling. The low oven temperature was used to help prevent structural changes in the wood. After 60% w/o water was added, the moist wood was placed in a refrigerator for 24 hours to allow the water to diffuse into the wood. The ozone contacting period was two hours. These conditions were chosen based on the recommendations by Chang.

After the ozone treatment was complete, the samples were combined with 200 ml of distilled water and stirred for periods of 12 hours at 60°C in an Erylenmeyer flask. The samples were then filtered in fritted glass funnels under a vacuum. The filter cakes were dried in an oven at 45°C and sent to the Animal Sciance Department for analysis or were disposed of. Fifty ml samples of the filtrate were subjected to various acid treatments to complete hydrolysis and were neutralized with either NaOH or NH_4OH to raise the pH to an acceptable level for analysis. The need for the pH adjustment is explained in the results.

Pretreatments Before Ozone Process

I. Water Contact

Ten grams of oven-dried (45°C) mesquite were mixed with 100 ml of distilled water at 60°C for 12 hours. The filtrate was analyzed for sugar content while the filter cake was dried in an oven (45°C) until constant weight was achieved. The dry filter cake was next contacted with 60% water by weight in a refrigerator overnight and exposed to ozone degradation as was previously described.

II. NaOH Contact

Ten grams of oven-dried mesquite were mixed with 100 ml NaOH (10 w/o) in an Erylenmeyer flask and stirred and heated at 60°C for 12 hours. The liquid and solids were then separated by successive centrifugations and finally by using vacuum filtration through fritted glass filters. The filtrate was analyzed for hemicellulose fractions. The filter cake was washed well with water until the pH was below 7 and oven-dried at 45°C. After constant weight was achieved, the sample was mixed with 60% w/o water and refrigerated overnight before ozonalysis.

III. Acetic Acid Pretreatment

Ten grams of oven-dried mesquite were added to 200 ml of 45% w/o acetic acid at 0°C and stirred for 30 minutes in a gas saturator. An ozone-oxygen mixture was then bubbled through a fritted glass sparger into the slurry for 1/2 hr. followed by vacuum filtration (Fig. 2). The filter cake is then heated at 60°C and stirred with 100 ml 2% w/o NaOH for 1 hr. The solution is vacuum filtered and washed repeatedly with distilled H_2O until the pH value of the filtrate is below 7.0. After drying, the filter cake was mixed with 60% w/o water and refrigerated.

IV. Combination NaOH and Acetic Acid

After 20 grams of dry mesquite were subjected to the 10 w/o NaOH extraction, it was washed well with warm water and combined with 200 ml (45%) acetic acid for further extraction. Normal pretreatment acetic acid procedures as previously described were then followed.

V. H_2SO_4 Pretreatment

Ten grams of oven-dried mesquite were stirred and heated with 100 ml 2% w/o H_2SO_4 at 100°C for 24 hours. The mixture was then vacuum filtered and the filter cake was washed and dried in an oven (45°C). The filtrate was analyzed for sugars.

Carbohydrate Analysis

Filtered extracts from mesquite samples were analyzed on a Waters Associates high pressure liquid chromatograph (HPLC) system which included a model 6000 A pump, differential refractometer, and model UGK injector. The column used was a Waters Associates Carbohydrate Analysis Column. Qualitative analysis was accomplished by noting the different retention times, T_R, various sugars take in traveling through the column. T_R is measured from the time the sample was injected to the time the peak reaches a maximum. Table 2 shows the retention times for five sugars. Figure 3 shows a standard chromatogram for the same five sugars.

Table 2. Retention Times of Sugars in HPLC

Conditions	Sugar	Mean Retention Times (T_R)
Temperature: ambient	Xylose	5.7
Solvent: CH_3CN/H_2O	Arabinose	5.9
Flow Rate: 1.5 ml/min	Mannose	7.6
Attenuation: 8 X (RI)	Galactose	8.9
Chart Speed: .5 in/min	Glucose	9.4
Pressure: 1000 psia		

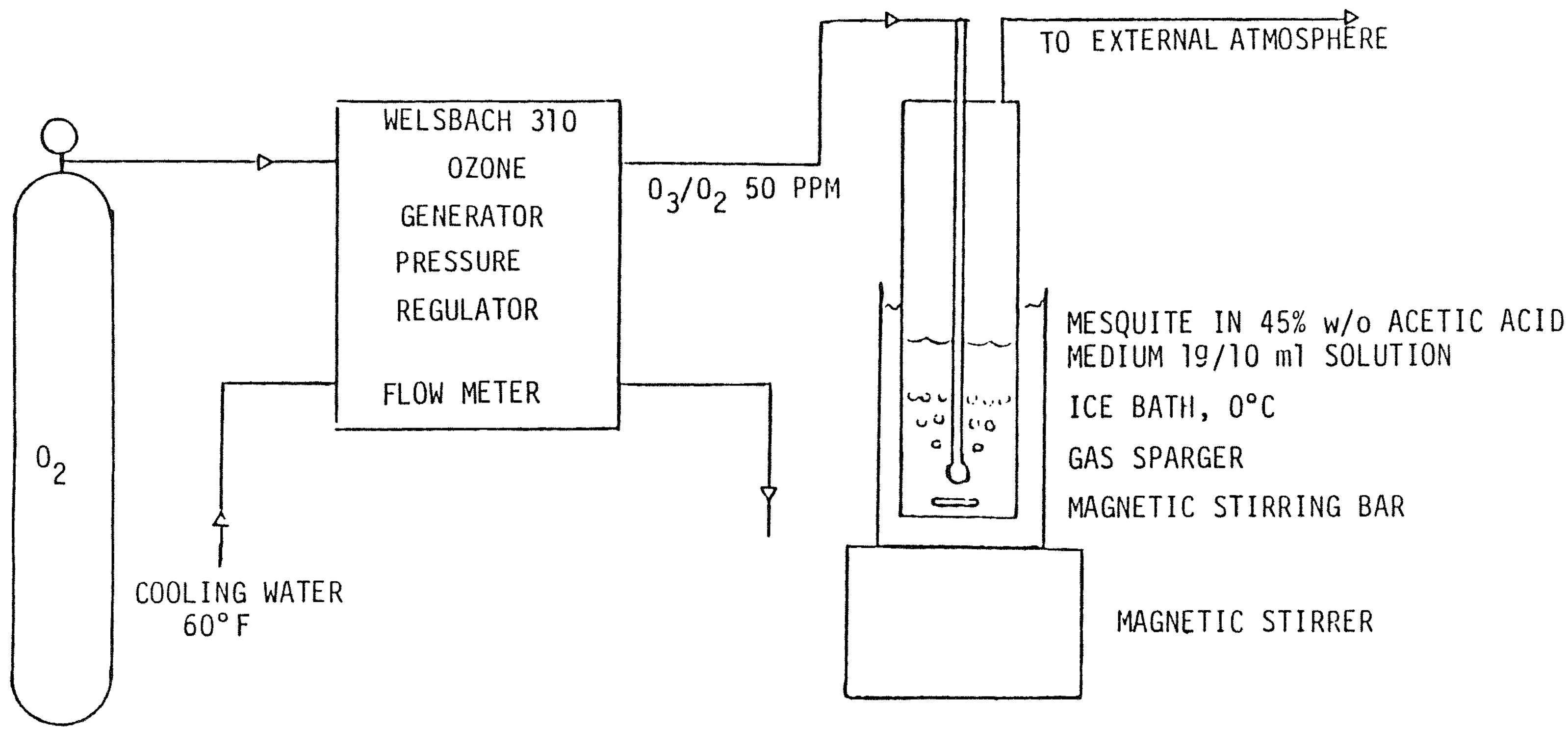


Figure 2. Apparatus for Liquid Phase Ozonalysis in 45% w/o Acetic Acid and Mesquite Slurry

Conditions:

Volume = 10 ml
Pressure = 1000 psia
Flow rate = 1.5 ml/min
Chart speed = .5 in/min
Solvent = CH_3CN/H_2O, 85/15
RI = 8X

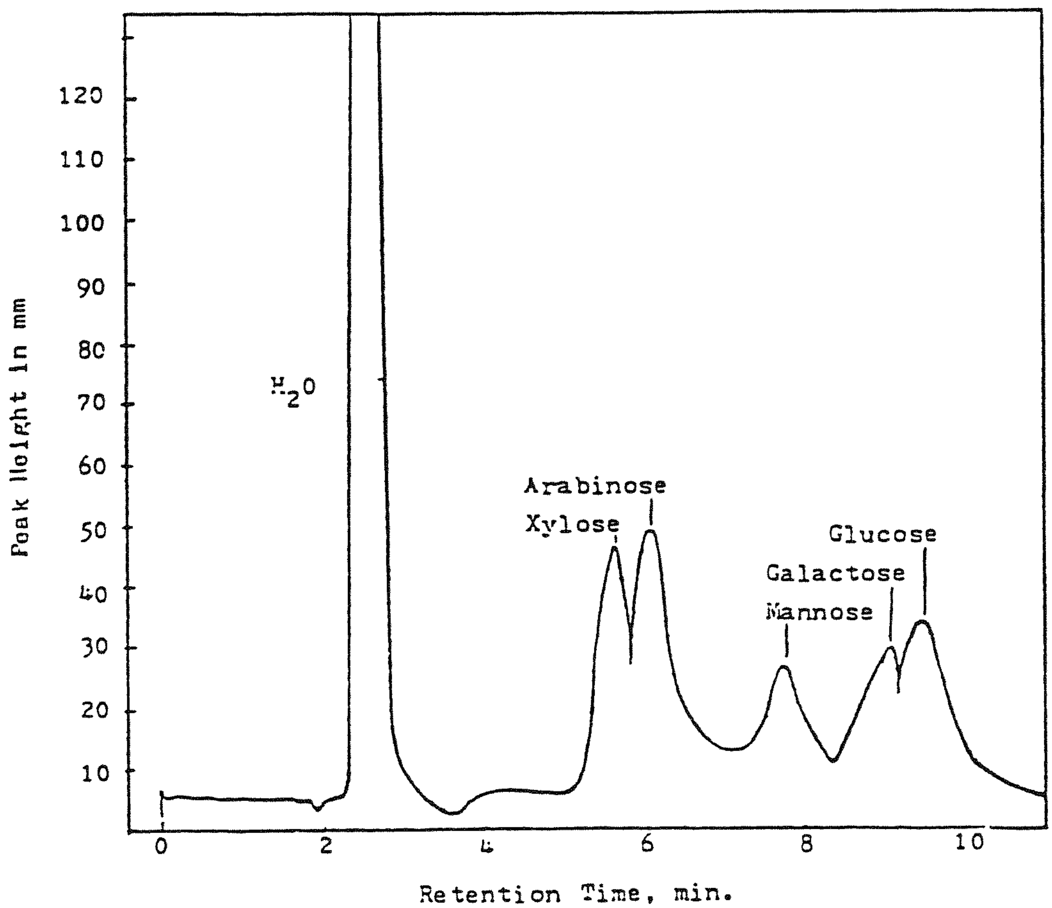


Figure 3. Standard Chromatogram for Five Suspected Sugars Using HPLC (Waters Associates Carbohydrate Analysis Column).

Quantitative analysis of each sugar was performed by approximating the area underneath the peak as a triangle and computing the area from the peak's height and band width. A standard calibration curve is prepared by injecting known concentrations of a standard into the column and calculating peak area. A plot is then made of concentration versus area. A sample of unknown concentration can then be quantified by calculating its peak area and finding the corresponding area of the calibration curve.

RESULTS AND DISCUSSION

A list of experimental groups was prepared based on chemical treatments used. A total of nine groups representing nine different treatment processes are given in Table 3.

Two major obstacles arose during the analysis of the filtrates. One problem was directly related to the adjustment of the sample pH. Typically the pH values had to be raised from their highly acidic value (1.5-2.5) just after ozonolysis to a value within the acceptable range for the carbohydrate column. Recommended operating instructions specified that samples should have pH values within a pH range of 3 to 7 in order to prevent irreversible damage to the precolumn filter and the main column. Solutions with a pH below 2.0 potentially could destroy the precolumn filter. Likewise, solutions with a pH value above 8 are capable of rapidly dissolving the packing in the main carbohydrate column. Therefore, bases were added to the filtrates in order to bring the pH to within the specification limits. The addition of the bases caused precipitates to form. It was suspected that the precipitates were aldoses which were condensing or repolymerizing to form insoluble polysaccarides. Evidence to support this hypothesis was obtained when one sample was inadvertently run at a pH of 1.5 and then later rerun at a pH of 4.5. The acidic sample displayed a distinct aldose peak on the chromatogram while the sample with the more basic pH value gave a chromatogram which was flat, thereby indicating an absence of sugars (Fig. 4).

Both NaOH and NH_4OH were tried as bases to elevate the pH levels in the filtrates. Neither base displayed any advantage in preventing the formation of precipitates and loss of soluble sugars. However, ammonium hydroxide was finally chosen based on its value as a nutrient in fermentation mixtures.

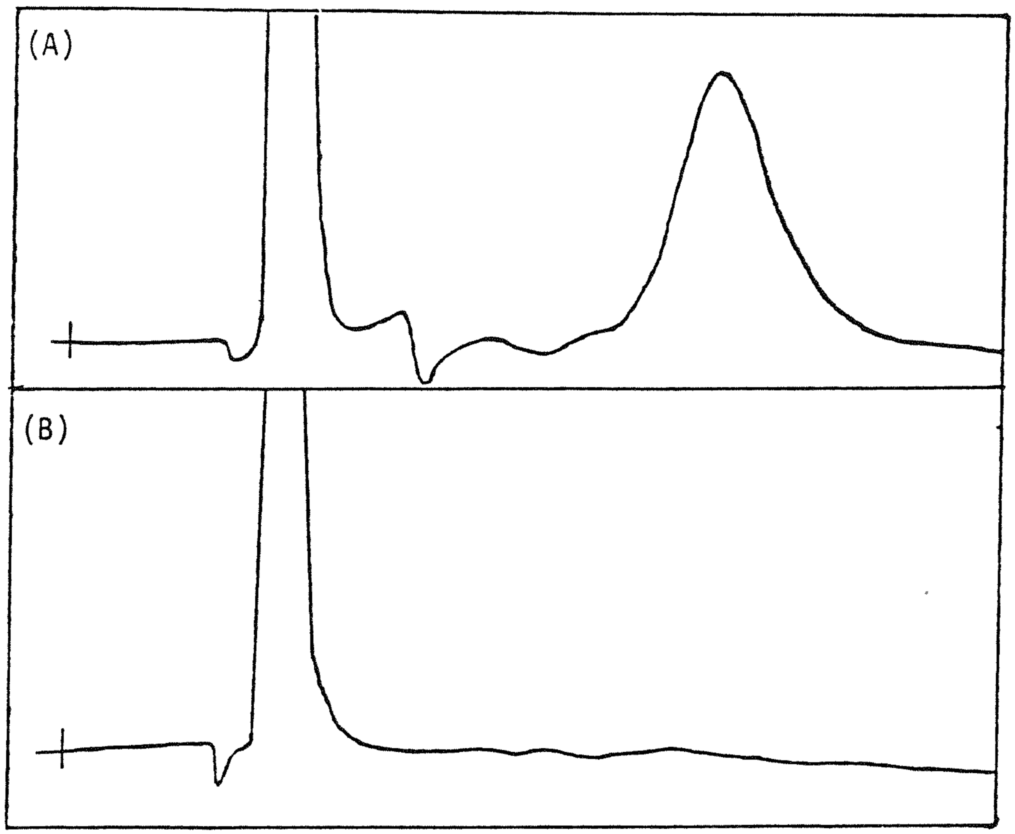
To help overcome the precipitation of oligomers in the experimental samples, additions of dilute hydrochloric acid and sulfuric acid were made. Hopefully the addition of strong acids would complete hydrolysis of the soluble oligomers before the bases were added to adjust pH. The addition of 1 ml 10% HCl per 50 ml of filtrate solution before the basic solution was added appeared to give the best results. However, it was demonstrated on standards of both xylose and glucose that these small amounts of HCl, when added to the samples, slightly shifted the peak re-

Table 3. Treatments Used for Sample Groups

Assigned Treatment Letter	Sample Group Designation	Description of Treatment Used
A	G-1	Oven-dried mesquite (45^{o}C) is contacted with 60% w/o distilled water and placed in a glass u-tube reactor at 0^{o}C. An oxygen-ozone (50 ppm) mixture flows through the tube for 2 hrs. at 2 liters/min. The sample is then heated and stirred with distilled water (200 ml) for 12 hrs.
B	G-2	Oven-dried mesquite (45^{o}C) is heated at 60^{o}C and stirred with distilled water (10 ml H_2O/g-mesquite) for 12 hrs. The slurry is then vacuum filtered and the filter cake is oven-dried. Treatment A then follows.
C	G-3	Oven-dried mesquite (45^{o}C) is heated at 60^{o}C and stirred with 10% w/o NaOH (10 ml/g) for 12 hrs. The slurry is centrifuged three times and then vacuum filtered. The filter is dried before Treatment A is implemented.
D	G-4	Oven-dried mesquite (45^{o}C) is stirred with 45% w/o acetic acid (20 ml/g) in a gas wash bottle (0^{o}C) while an oxygen-ozone (50 ppm) mixture is sparged into the slurry at 2 liters/min. After 30 min. the slurry is vacuum filtered and washed with distilled water. The filter cake is then heated at 60^{o}C and stirred with 2% w/o NaOH for 1 hr. The mixture is vacuum filtered and washed with distilled water again. The filter cake is dried and submitted for Treatment A.
E	G-5	Treatment C is followed by Treatment D for 1/2 to 4 hrs. and finally Treatment A is used.
F	G-6	Oven-dried mesquite (45^{o}C) is heated (100^{o}C) and stirred with 2% w/o H_2SO_4 (10 ml/g) for 24 hrs. The mixture is filtered and the filter cake is oven-dried.
G	G-7	Treatment F is followed by Treatment D and finally by Treatment A.

Table 3. (continued)

Assigned Treatment Letter	Sample Group Designation	Description of Treatment Used
H	G-8	Treatment H is identical to Treatment D with the exception that 100% w/o acetic acid is used in place of 45% w/o acetic acid.
I	G-9	Treatment C is followed by Treatment D (8 hours) and finally to Treatment A.



(A) Sample SB15 from group G-4 filtrate left at pH 1.5.

(B) Sample SB15 from group G-4 filtrate after addition of 10% NaOH, pH 4.5.

Figure 4. Comparison of Unadjusted and Adjusted pH for Sample HPLC Chromatograms

tention times. Also, the addition of 2 ml of more concentrated HCl per 50 ml filtrate solution resulted in numerous new chromatogram peaks at various retention times.

The second major problem with the carbohydrate analysis involved the day-to-day fluctuation of retention times for both glucose and xylose. Retention times varied little when samples were run on the same day. To overcome these problems, a statistical approach was employed.

The probability that any group of samples did in fact contain glucose was determined using the values of t and N-1 and using Table 1-22 in Perry's Chemical Engineering Handbook, 5th ed., page 1-40. It was decided that any test with a probability below 95 percent would be rejected, which would leave that sample peak unidentified. In addition, the total amounts of aldoses extracted were calculated from the standard calibration curves prepared previously. These values are listed in Table 4.

Peaks with mean retention times not in any acceptable carbohydrate ranges are listed in Table 4. There are a large number of compounds which might have been responsible for these peaks, including methylated and chlorinated sugars, ozone cleaved aldose rings, and carbohydrate salts. These suggestions are speculatory and have not been proven experimentally.

Also listed in Table 4 are data for *in vitro* digestibility and percentage of total weight loss. The IVDMD values were averaged from those prepared by the Department of Animal Sciences. These data are only suggestive of potential levels of cellulose left in the dried filter cake samples which were submitted for analysis. The digestibility level is determined by measuring the fraction of the organic portion of sample that dissolves after microorganisms are allowed to react with the sample for a prescribed number of days. This procedure is designed to simulate the digestive processes of ruminant animals and is extensively used to evaluate ruminant rations. As shown in Table 4, the IVDMD levels reported were unusually high for mesquite, i.e.>60%. This can be misleading, but indicates what is happening during the treatment process. One must first realize that many nutrients in the hemicellulose portion of mesquite have already been extracted along with some of the cellulose. Secondly, the digestibilities increase as the number of extractions used increased. When NaOH, acetic acid, and gas phase ozone treatments were implemented successfully on the mesquite, the IVDMD value was twice that of raw mesquite. In two samples the digestibility levels approached 90%. This suggests that a large fraction of high purity cellulose remained in the filter cake and that most of the lignin-cellulose bonds had been cleared. This fact was supported by the formation of what appeared to be cellulose pulp in the dried filter cakes. In comparison, the ozone and water hydrolysis of the biomass matrix appears to be much less effective in reference to the IVDMD results.

As mentioned earlier, the HPLC results appear even less promising with regard to sugar production. Ozonalysis of unextracted mesquite (60% w/o

Table 4. List of Results for Experimental Groups

Sample Group	No. of Samples	Probability Glucose	Glucose Extracted (Mean)g/g	Probability Xylose	Xylose Extracted (Mean)g/g	% IVDMD (Mean)	%* Wt. Loss	Unidentified** Peaks
G-1	9	.99	6.25×10^{-3} 10.003	> .01	0 0	45.0	25%	7.1
G-2	3	> .01	0 0	> .01	0 0	47.9	40%	7.1
G-3	4	> .01	0 0	> .0	0 0	49.0	45%	7.8
G-4	4	.98	1.0 15.0	> .01	0 0	71.6	48%	-
G-5	6	> .01	0 0	.99	.88 20.08	71.7	66.4%	4.6, 7.4
G-6	3	.95	.25 10.0	.98	.88 10.01	--	58%	8.7
G-7	3	> .01	0 0	> .01	0 0	--	69%	7.3
G-8	3	> .01	0 0	> .01	0 0	--	42%	5.1
G-9	2	.68	1.2 20.03	> .01	0 0	--	73%	8.1

*Wt. Loss on % Dry Basis.

**Mean Retension Time in Min.

H_2O, G-1) resulted in a negligible amount of glucose being extracted according to the chromatogram. This result was not unexpected. It was suspected that the lack of such activity might be due to the interference of the hemicellulose and the normal lignin-cellulose bonding. It is apparent that some additional chemical means will be necessary if the ozone-water hydrolysis of cellulose is to occur to any appreciable degree. The use of hot water extraction prior to the gas phase ozone reaction was even less effective in completing the hydrolysis, however, this was probably due to the condensation effects produced during the heating and drying cycles experienced by the wood. The mesquite structure could have condensed while drying to an even tighter matrix than the untreated samples. It is to be noted that some difficulty was observed in attempting to regrind the woody biomass filter cake after the water extraction.

The negative results which were observed for preextraction of the wood with 10% w/o NaOH create many new questions concerning the hydrolysis of mesquite with the aid of an ozone-oxygen mixture. Assuming the caustic extraction removed a major protion of the hemicellulose, the ensuing hydrolysis should have produced at least modest amounts of glucose. That is, with the hemicellulose fraction reduced, the lignin should have been more susceptable to ozonalysis than raw mesquite. Again however, the heating and drying effects could have caused the woody matrix to tighten. Also, other studies have shown that caustics can destabilize the ozone, resulting in a lower O_3 concentration (Allen, 1981). It was observed that extremely hard and tightly bound woody chunks are produced following the NaOH extraction. This woody conglomerations were much harder to regrind than those samples extracted only with water. This suggests that the matrix condensation is not totally due to the heating and drying effects. Sodium hydroxide seems to chemically alter the woody structure to inhibit further degradation by water and ozone.

The NaOH-mesquite slurries were extremely difficult to filter. Several successive centrifugations were required before the slurries could be separated into solid and liquid fractions by a final vacuum filtration. It should be noted that 4 hr. extraction produced very similar results to 12 hr. extractions.

Those experiments which used a liquid slurry medium of 45% w/o acetic acid and mesquite as a pretreatment prior to the gas-phase reaction did produce promising results. Approximately 1 gram of glucose was extracted from 15 gram samples of dry mesquite. Since approximately 37% of mesquite is cellulose, the results show that almost 18% of the potential glucose was extracted. The acetic acid pretreatment also had many advantages over the other processes which were attempted. First, the time required was only 30 min., compared to 12 hrs. for the other preextraction methods. Second, the resulting slurry was easily filtered. Last of all, the filter cake, after drying, was easily reground to (24-40) mesh size. The only major problem that occurred with the slurry pretreatment was foaming. This was probably due to surface effects by minor constituents in raw mesquite. If mesquite biomass was extracted with water, NaOH, or sulfuric acid before the acetic acid pretreatment, foaming did not occur. A small addition of an antifoaming solution from DOW (DB-31 Antifoam Emulsion) also solved the problem immediately.

Removing the hemicellulose before implementing the acetic acid pretreatment seems a logical step. A sodium hydroxide (10% w/o) extraction was implemented before the slurry pretreatment was used. The results however, were negative with respect to glucose production. Apparently the heated sodium hydroxide treatment causes stronger inhibitory effects than does the presence of the hemicellulose. It was noted that after eight hours of ozonalysis in the acetic acid and (NaOH extracted) mesquite slurry, modest amounts of glucose were extracted. No noticable levels of glucose were noted when less than eight hours of ozonalysis of the NaOH extracted mesquite slurry was implemented. This additional amount of time for ozone contact necessary to extract glucose further shows the inhibitory effects of sodium hydroxide of ozone hydrolysis of mesquite biomass.

95% acetic acid w/o was tried as a medium for the liquid phase reaction with ozone and mesquite, but these results were also negative. This was not unexpected since Mbachu and Manley (1981) had already determined 45% as the optimum concentration. This confirms the necessity for water to be present in the liquid phase lignin degradation in mesquite.

Extraction of the mesquite with 2% w/o H_2SO_4 had the same effect as did the other extractive methods. The following ozone hydrolysis failed to produce any significant extracted glucose. The sulfuric acid did apparently extract approximately 40% of the potential hemicellulose and five percent of the potential glucose. These results were expected as acid hydrolysis is a common procedure for pentose and hexose removal from biomass. It should be noted that the time of H_2SO_4 extraction used was much too long and pentose fractions extracted were not necessarily the optimum. The 24 hr. period was intended to be used as an extreme to ensure maximum pentose removal. This was not true in this case.

Weight Loss

A weight loss on a percent dry basis was calculated for each sample group (Table 4). The dry weight of the filter cake after treatment was subtracted from the dry weight of the sample to obtain the mass lost. If all the sample chromatogram peaks could have been determined qualitatively and quantitatively a complete mass balance could have been employed. A total sugar concentration could have also been determined from spectrophotometric analysis to obtain an overall mass balance but this was not done. The weight loss calculations do indicate the total weight extracted from the different sample groups. The H_2SO_4 treatment followed by gas phase ozonalysis extracted 69% of the dry wood weight, compared to 66, 48, 45, and 40% for NaOH-acetic acid-ozonalysis, acetic acid-ozonalysis, NaOH-ozonalysis, water-ozonalysis, respectively. NaOH extraction followed by eight hours of acetic acid treatment followed by ozonalysis extracted 73%

of the dry mesquite weight. The resulting filter cake of this sample dried to a paper like substance that presumably had a high cellulose content. There was little correlation between percent weight loss and glucose extracted.

Cost of Producing Glucose from Ozone Processed Mesquite

A preliminary plant design was prepared for the production of a 5% w/o glucose solution from 3.7 kg/sec (350 ton/day) of air-dried mesquite. Hypothetically it will produce 7.62 x 10^6 kg (8400 tons) per year of glucose in 5% w/o solution. The overall design consisted of four reactor batteries, two filtration and wash units, one ozone generator, one rotary dryer, one storage silo, seven conveyor systems, eight pumps, one shell-and-tube heat exchanger, and four large pulverizers (see Fig. 5).

The total capital cost of this plant was estimated to be five million dollars and have a twenty year life. A large portion of this expense was due to the 1.5 million dollar cost of the Pandia reactor. Annual energy, materials, and labor costs were estimated to run 1.3 million, 3 million, and .5 million dollars per year, repsectively. The major component of the material cost estimate was the 28¢/kg ($21/ton) cost of delivered mesquite (Cauble, 1978). An annual operating cost was calculated to be approximately 4.7 million dollars per year in 1981 dollars. On this basis the cost to produce 1 kg of glucose in 5% w/o solution was 61 cents ($.28/lb).

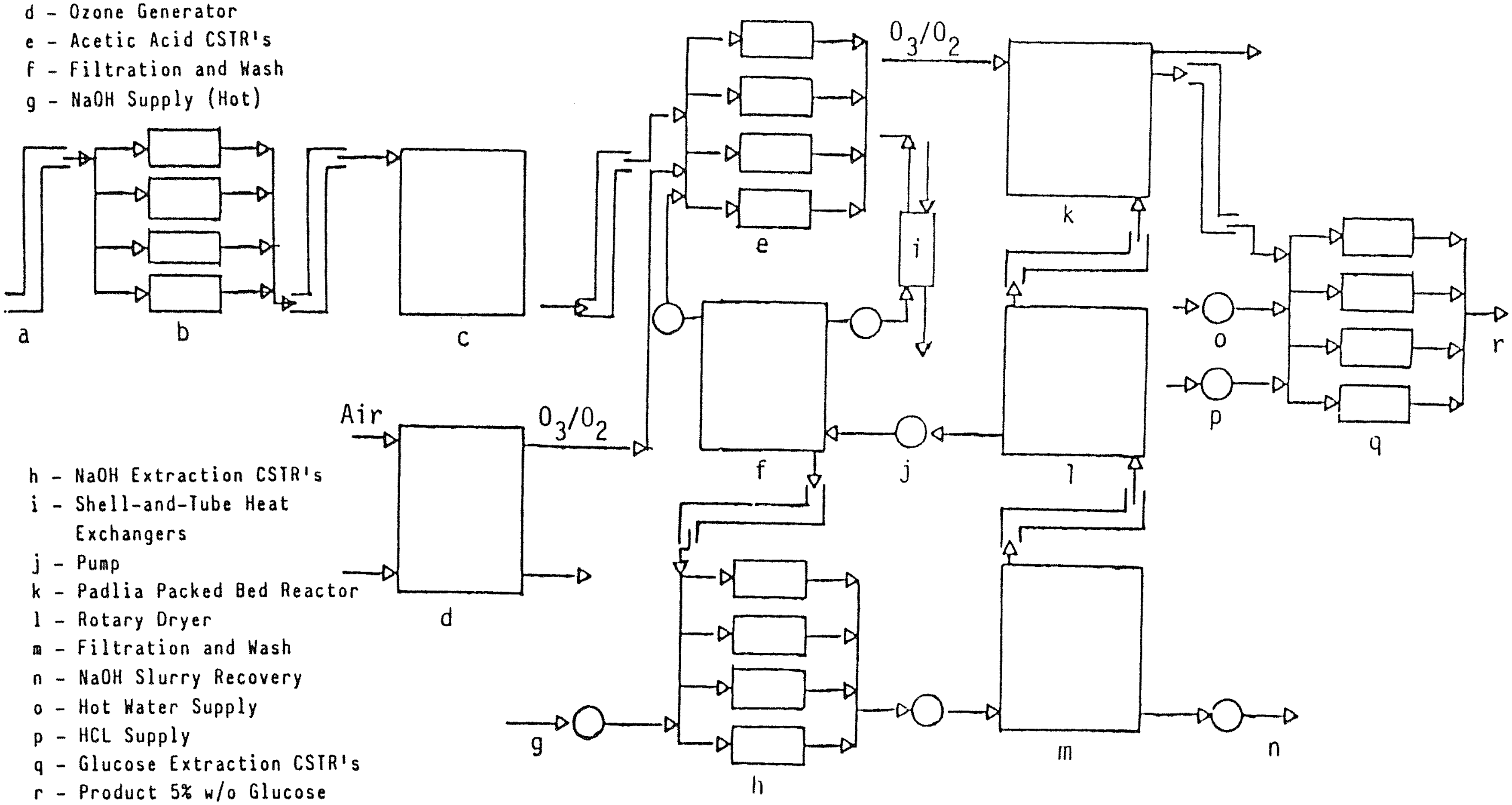
When compared to the Madison Process (Wilke, 1980) of using mild acid hydrolysis of cellulose and extraction of glucose from wood, the ozone process appears very uneconomical. The cost of producing sugars in 5% concentration has been estimated at seventeen cents per kg ($0.075/lb) in 1981 dollars. Cysewski (1976) estimated that the sugar cost of a 5% concentration and must be reduced to 8-10 cents per kg (4-5 cents/lb) for fermentation ethanol processes to be economically viable. One would conclude, therefore, that the ozone process considered in this thesis is a less economical method for producing sugars in 5% concentrations from wood and is far from being economically viable.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

From the results of this study I have concluded that a combination of a 45% acetic acid and mesquite slurry with an ozone-oxygen mixture sparged through at 0°C followed by a gas-phase ozonalysis with mesquite and 60% w/o H_2O at 0°C is the most promising method for producing glucose of the various techniques studied. This method resulted in the removal of 18% of the potential glucose in a total of 2 and 1/2 hours of ozone contact. The resulting solutions produced by this approach were also the simplest

a - Conveyor
b - Pulverizers
c - Storage Silo
d - Ozone Generator
e - Acetic Acid CSTR's
f - Filtration and Wash
g - NaOH Supply (Hot)



h - NaOH Extraction CSTR's
i - Shell-and-Tube Heat Exchangers
j - Pump
k - Padlia Packed Bed Reactor
l - Rotary Dryer
m - Filtration and Wash
n - NaOH Slurry Recovery
o - Hot Water Supply
p - HCL Supply
q - Glucose Extraction CSTR's
r - Product 5% w/o Glucose

Figure 5. Preliminary Plant Design for the Production of a 5% w/o Glucose Solution from 3.7 kg/sec (350 tons/day)

to filter and the solids were the easiest to regrind. Observing the cost estimates, this process does not appear to be economically viable.

Recommendations

I recommend that further research be conducted towards the optimum conditions for the liquid phase mesquite reaction. The effect of temperature and time of contact with ozone need to be pinpointed in order to improve the poor economics for this process. Optimum catalyst and acid studies by Steven Fish (1982) for the gas phase reaction should be combined with results for liquid phase conditions to determine if this process can be economically viable.

LITERATURE CITED

Allen, B. R., Cousin, M. J. and Pierce, G. E.: "Pretreatment Methods for the Degradation of Lignin," Battelle, Columbus Lab, Columbus, OH: 12-14 (1980).

Beck, Steven R. and Tuttle, Richard J.: "Glucose Production by Biochemical Hydrolysis of Mesquite," AIChE Journal, 25(5): 890-892 (1979).

Beck, Steven R. and Wang, Ta-Sheng (David): "Kinetic Analysis of Hemicellulose Hydrolysis in Cotton Gin Residue," AIChE National Meeting, Orlando, Florida, Feb. 28-Mar. 3 (1982).

Berry, R. I.: "Wood-to-Ethanol Methods Edge Closer to Fruition," Chem. Eng., 88(2): 51-55 (1981).

Bolkner, H. I., Rhodes, H. E. W., Lee, K. S.: "Degradation of Insoluble Lignin by Chloride Monoxide," J. Agr. Food Chem., 25(4): 708-716 (1977).

Brauns, F. E. and Brausn, D. A., The Chemistry of Lignin, Academic Press, New York: 67-75 (1960).

Caugle, Douglas G.: "A Cost Analysis of Alternative Methods of Mesquite Harvesting," M.S. Thesis, Texas Tech University, Lubbock, TX (1978).

Chang, J.: "Comparison of Mesquite Thermal Chemical Treatment for a Ruminant Ration," M.S. Thesis, Texas Tech Univerisyt, Lubbock, TX (1981).

Cysewski, G. R. and Wilke, C. R.: "Utilization of Cellulosic Materials Through Enzymatic Hydrolysis. I. Fermentation of Hydrolysate to Ethanol and Single Cell Protein," Biotech. Bioeng., 18: 1297-1313 (1976).

Derrick, David G. and Perrich, Jerry R.: "Guide to Ozone Equipment Selection," Pollu. Eng.: 42-44 (1979).

Fish, S. J., "Increasing the In Vitro Digestibility of Mesquite with Inorganic Catalyst and Ozone," M.S. Thesis, Texas Tech University, Lubbock, TX (1982).

Goring, D. A. I.: "Some Aspects of the Topochemistry of Lignin in Softwood and Hardwood," Int. Symp. Wood Pulping Chem., 1: 3-10 (1981).

Hall, R. S., Matley, J. and McNaughton, K. J.: "Current Costs of Process Equipment," Chem. Eng., 89(7): 80-116 (1982).

Hauley, L. F. and Wise, Louis E.: The Chemistry of Wood, American Chemical Society Monograph Series No. 28, The Chemical Catalog Company, Inc., New York, NY (1926).

Kiryushina, M. F. and Tischenko, D. V.: "Ozonation of Wood as a Method of Studying Nature of Chemical Bonding Between Lignin and Carbohydrates," Zhur. Prikl. Khim., 44(1): 159-167 (1971).

Kratzl, K., Claus, P. C. and Reichel, G.: "Reactions of Lignin and Lignin Model Compounds with Ozone," Tappi, 59(11): 1011-1021 (1976).

Lantican, D. M., Cote, W. A. Jr. and Skaar, Christen: "Effect of Ozone Treatment of the Hygroscopicity, Permeability and Ultrastructure of the Heartwood of Western Red Cedar," Ind. Eng. Chem., Prod. Res. Dev., 4(2): 60-70 (1965).

Mbachu, R. A. D. and Manley, R. St. John: "Degradation of Lignin by Ozone. I. The Kinetics of Lignin Degradation of Ozone," J. Polym. Sci.: Polym. Chem. Ed., 19(8): 2053-2063 (1981).

Mbachu, R. A. D. and Manley, R. St. John: "Degradation of Lignin by Ozone. II. Molecular Weights and Molecular Weight Distribution of the Alkali-Soluble Degradation Products," J. Polym. Sci.: Polym. Chem. Ed., 19(8): 2065-2078 (1981).

Moore, Wayne E., Efflund, Marilyn J. and Millett, Merrill A.: "Hydrolysis of Wood and Cellulose with Cellulytic Enzymes," J. Agr. Food Chem., 20(6): 506-511 (1973).

Morrison, R. T. and Boyd, R. N.: Organic Chemistry, 3rd Ed., Allyn and Bacon, Inc. (1973).

Nelson, Russell and Conrad Schuerch: "The Extractions of Pentosans from Woody Tissues, II," Tappi, 40(6): 419 (1957).

Peters, M. S. and Timmerhaus, K. D.: Plant Design and Economics for Chemical Engineers, 3rd Ed., McGraw-Hill Book Co. (1980).

Sands, L., Nutter, Lila and Pauline: "The Hemicelluloses Extracted from Mesquite Wood After Chlorination," J. Bio. Chem., 110: 17-22 (1935).

Schuerch, C.: "Ozonation of Cellulose and Wood," J. Polym. Sci., 2(c): 79-95 (1963).

Schuerch, C.: "The Resistance of Hemicelluloses in Wood Fiber to Degradation by Ozone," Tappi, 49(5): 206-209 (1966).

Schuerch, Conrad and Katai, A. A.: "Mechanism of Ozone Attach on α-Methyl Glucoside and Cellulosic Material," J. Polym. Sci., 4: 2683-2702 (1966).

Schuster, Joseph L.: Literature on the Mesquite (Prosopis L.) of North America: An Annotated Bibliography, International Center for Arid and Semi-Arid Land Studies, Special Report No. 26, Texas Tech University, Lubbock, TX (1969).

Vernor, T. E.: "Processing of Mesquite for Cattle Feeding," M.S. Thesis, Texas Tech University, Lubbock, TX (1977).

Whistler, R. L. and BeMiller, J. N.: "Solubility of Polysaccharides and Their Behavior in Solution," Adv. Carbohydrate Chem., 13: 289-298 (1958).

Wilke, Charles R.: "Production of Sugars and Ethanol Based on the Enzymatic Hydrolysis of Cellulose," Proc. of Fuels Biomass Symp., (COO14225-1): 115-144 (1977).

INCREASING THE <u>IN VITRO</u> DIGESTIBILITY OF MESQUITE WITH INORGANIC CATALYSTS AND OZONE[1]

S. J. Fish[2], R. W. Tock and C. R. Richardson

Abstract[3].--Seven inorganic catalysts, used in combination with ozone and water, were studied to determine the effects they had on the *in vitro* dry matter digestibility (IVDMD) of mesquite biomass. These catalysts include: vanadium pentoxide, manganese sulfate, ferric oxide, cupric oxide, rubidium chloride, strontium chloride, and molybdenum trioxide. The effects of other process variables, i.e. time, temperature, and the addition of acid were also studied. The results indicate that the molybdenum trioxide and rubidium chloride both increased the digestibility of mesquite significantly over that obtained from ozone treatment alone. The remaining catalysts had less effect on the IVDMD, with several catalysts actually decreasing the digestibility. Using the molybdenum trioxide (400 ppm) as a base, the effects of other process variables were studied. From the temperature studies the optimum initial reactor temperature should be about 0°C, while two hours yielded the optimum time of ozone contact. From the acid studies, molybdenum trioxide used in combination with sulfuric acid yielded the best results. The other acids, hydrochloric, nitric and acetic, also increased the digestibility above that obtained with only ozone, but did not yield results which were comparable to the sulfuric acid.

Scope

Preparing ruminant rations from wood is not a new idea, but is has not been widely used due to the inaccessibility of the cellulose and hemicellulose in the woody structure. The lignin in the wood incrusts the holocellulose thus making only a small percentage of the holocellulose accessible to the rumen bacteria. Many methods have been studied on various species of woods in an attempt to increase the digestibility of the wood. Baker et al. (1975) lists several of these methods and their affect on the IVDMD. Mesquite wood was not included in Baker's study, since it is common only to the semi-arid regions of the Southwest. There have been several attempts to increase the digestibility of mesquite through thermochemical modifications. These methods include sulfur dioxide treatment. Parker et al. (1977), Vernor (1977), and Fahle (1978) all reported results obtained from SO_2-water treatment. Albin (1976) investigated the use of caustic as a chemical agent for the treatment of mesquite biomass. Tock et al. (1982) and Chang (1981) both report the results of an experimental study using ozone in combination with water to treat the mesquite biomass.

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The use of ozone was shown to increase the IVDMD from about 25% for untreated mesquite to approximately 60% for ozone treated mesquite under the conditions described by Chang (1981).

This paper reports the results of an experimental program investigating the use of ozone and inorganic catalysts in combination with water to treat mesquite wood to produce a ruminant feed. The measure of success was the level of *in vitro* dry matter digestibility achieved by the treatment process.

Conclusions and Significance

In vitro dry matter digestibilities were obtained for mesquite biomass under various treatment conditions. Seven different inorganic catalysts were studied in combination with water and ozone. The molybdenum trioxide increased the IVDMD from a level of 26% for raw untreated mesquite to approximately 58% when 400 ppm MoO_3 were added and the mixture treated with ozone for 2 hours. Rubidium chloride also increased the IVDMD to a value of 57% for a 1000 ppm RbCl addition to the sample. Strontium chloride produced a maximum value of approximately 52%. The manganese sulfate results were about 54% for low concentrations (<100 ppm) of $MnSO_4$. The remaining three catalysts vanadium pentoxide, ferric oxide, and cupric oxide all produced digestibilities which were in the range of those obtained by the use of an ozone treatment alone. Several of these results were lower than the 41% IVDMD obtained solely by O_3 treatment (i.e. 10 ppm V_2O_5: 39% IVDMD, 500 ppm CuO: 32% IVDMD and 1000 ppm Fe_2O_3: 37% IVDMD). This tends to indicate the rumen bacteria are poisoned or inhibited by the metals. Table 1 gives the results obtained for all the catalysts and the concentrations studied. The affect of the molybdenum trioxide on the digestibility level was also studied without the benefits of ozone treatment. For untreated mesquite with 250 ppm MoO_3 the resulting digestibility was approximately 32%. When a 250 ppm MoO_3-mesquite sample was contacted with oxygen for 2 hours a 32% IVDMD was obtained. This tends to indicate oxygen alone has little or no effect on the digestibility. Table 2 lists the results obtained for various other conditions using MoO_3 as the catalyst.

Using 400 ppm MoO_3 as a control, the effects of various acids were studied. Sulfuric acid increased the digestibility from approximately 58% to a value of 71% for a 1:1 H_2SO_4/H_2O ratio. This value indicates that some of the lignin or extractives were being solublized by the acid. Nitric acid yielded a 60% digestibility for a 1:1 HNO_3/H_2O mixture. Hydrochloric acid produced the highest digestibility (68%) when a 3:4 HCl/H_2O mixture was used. The lowest digestibilities were obtained using acetic acid with the values about the same or lower than the 400 ppm MoO_3-O_3 treated mesquite. These values (i.e. 1:1 acetic acid/H_2O yielded a 53%) indicate that the acetic acid inhibits either the ozone reaction with the mesquite or inhibits rumen activity.

Table 1. Comparison of different catalysts and the resulting digestibilities

Catalyst	Concentration (ppm)	%IVDMD*
V_2O_5 (1)	10	38.90
	100	42.70
	1000	53.90
CuO (1)	10	43.00
	100	45.80
	500	32.00
	1000	34.90
Fe_2O_3 (1)	10	39.60
	100	41.40
	1000	37.00
$MnSO_4$	10	54.59
	50	51.00
	100	54.47
	250	47.36
	500	47.91
	1000	49.23
RbCl	10	56.72
	50	54.74
	100	57.15
	250	57.03
	500	53.89
	1000	57.57
$SrCl_2$	20	51.27
	50	52.08
	100	52.12
	250	52.39
	500	52.65
	1000	54.56
MoO_3	10	58.47
	50	55.66
	100	56.00
	250	55.76
	400	58.59

Reactor temperature: 32^{o}F (^{o}C)
Reaction time: 2 hours
Mesh size: 40

Untreated mesquite: 26.39 %IVDMD
Ozone treated mesquite: 41.26 %IVDMD

*Values reported, only first two digits are significant.
[1] Values reported by Chang (1981). Each catalyst was dissolved in a slightly acidic medium.

Table 2. Comparison of the in vitro digestibility of mesquite under various conditions using molybdenum trioxide

Sample	Catalyst Conc. (ppm)	IVDMD*
Untreated	--	26.39
Untreated	50	29.60
Untreated	250	31.90
Untreated	400	34.67
O_2 Treated	50	28.95
O_2 Treated	250	31.65
O_3 Treated	50	55.66
O_3 Treated	250	55.76
O_3 Treated	400	58.59
O_3 Treated**	400	53.08

Reactor temperature: 32°F (0°C)
Reaction time: 2 hours
Mesh size: 40

*Values reported, only first two digits are significant.

**Catalyst added after ozone treatment.

The variation of ozone contacting time was studied. From the studies a maximum level of digestibility was obtained after a 2 hour ozone contacting time.

The effect of particle size was also investigated. Three different mesh or particle sizes were studied: 10, 24, and 40 mesh. The small particles yielded the highest digestibilities (40 mesh gave a 58% digestibility).

The final process variable studied was the initial reactor temperature. The results indicate that the lowest temperature studied (0°C) gave the highest digestibility (58%).

Tables 3, 4, 5, and 6 give the results of the acid addition, time, particle size, and temperature respectively.

These results indicate that treatment of mesquite biomass with ozone and inorganic catalysts in the presence of water make the holocellulose more accessible to the rumen bacteria. This form of pre-treatment applied to mesquite or any other type of biomass might lead to a method in which cellulosic wastes can be treated to produce a useful product.

With mesquite being so plentiful in the Southwest, a method to help offset the cost of eradification of the mesquite from the rangeland is currently being sought. Work has been under way at Texas Tech University for several years to find such methods. Work has ranged from the use of

Table 3. Comparison of acid concentration and the *in vitro* digestibility

Sample	Acid/Water[b]	%IVDMD*
Untreated	0	26.39
O_3 Treated	0	41.26
O_3 Treated[a]	0	58.59
O_3 Treated[a]	0.248[c]	47.50
O_3 Treated[a]	0.492[c]	52.15
O_3 Treated[a]	0.739[c]	68.10
O_3 Treated[a]	0.958[c]	56.92
Untreated	0.753[c]	42.02
O_3 Treated	0.753[c]	48.87
O_3 Treated[a]	0.244[d]	48.33
O_3 Treated[a]	0.477[d]	56.35
O_3 Treated[a]	0.733[d]	60.20
O_3 Treated[a]	0.977[d]	60.18
Untreated	0.748[d]	59.67
O_3 Treated	0.748[d]	59.40
O_3 Treated[a]	0.241[e]	35.67
O_3 Treated[a]	0.488[e]	57.01
O_3 Treated[a]	0.702[e]	58.00
O_3 Treated[a]	0.932[e]	53.17
Untreated	0.740[e]	32.33
O_3 Treated	0.740[e]	50.84
O_3 Treated[a]	0.246[f]	59.84
O_3 Treated[a]	0.470[f]	57.26
O_3 Treated[a]	0.733[f]	62.17
O_3 Treated[a]	0.978[f]	71.30
Untreated	0.720[f]	44.01
O_3 Treated	0.720[f]	54.01

Reactor temperature: 0 °C; Reaction Time: 2 hours; Mesh Size: 40
*Values reported, only first two digits are significant.
(a) Samples contain 400 ppm MoO_3
(b) Ratio of weight of acid to weight of water
(c) Hydrochloric Acid
(d) Nitric Acid
(e) Acetic Acid
(f) Sulfuric Acid

Table 4. Comparison of time and the *in vitro* digestibility

Time (Hours)	%IVDMD*
0	36.60
0.5	44.86
1	52.55
2	58.59
4	52.39
8	51.64
24	58.83

Reactor temperature: 32°F (0°C)
Mesh size: 40

All samples contain 400 ppm MoO_3

*Values reported, only first two digits are significant.

Table 5. Comparison of particle size and the *in vitro* digestibility

Mesh Size	%IVDMD*
10	34.92
24	38.25
40	58.59

Reactor temperature: 32°F (0°C)
Reaction time: 2 hours

All samples contain 400 ppm MoO_3

*Values reported, only first two digits are significant.

Table 6. Comparison of the temperature and the *in vitro* digestibility

Sample	Temperature (°F)	%IVDMD*
Untreated	--	26.39
O_3 Treated[a]	32	58.59
O_3 Treated[a]	Room Temperature (70)	51.27
O_3 Treated[a]	212	29.94[b]

Reaction time: 2 hours
Mesh size: 40

(a) Samples contain 400 ppm MoO_3
(b) Ozone ignited and the mesquite began to burn. This low value may be due to the burning which took place.

*Values reported, only first two digits are significant.

sulfur dioxide (Parker et al., 1977) to the use of caustic (Albin, 1976) to treat the mesquite so it could be incorporated into the ruminant ration. Work using ozone as the thremochemical treatment agent began in 1980 (Tock et al. 1982) with favorable results obtained. The continuation of this work with the addition of inorganic catalysts and the controlled variation of several process variables is the subject of this paper.

Experimental

The catalyst-ozone treatment was carried out in a bench-scale reactor system (Fig. 1). The catalyst solution was prepared by dissolving the appropriate catalyst in water. It was from this stock solution that the various concentrations of the catalyst with respect to the mesquite being treated were made.

The mesquite was dried then the catalyst solution and make-up water were added until a 60% by weight (with respect to the bone dry mesquite) mixture was obtained. This mixture was allowed to soak in a refrigerator for at least 24 hours. The preconditioned mixture was then placed in the reactor where the ozone-oxygen (water saturated) gas mixture contacted the mesquite for 2 hours. After treatment the mixture was dryed in a 48°C oven. The samples were given to the Texas Tech University Department of Animal Sciences for the digestibility determination.

For the variation of the process variables, the procedure was the same except that the specific variable in question, i.e. time, temperature, addition of acid, or particle size, was changed.

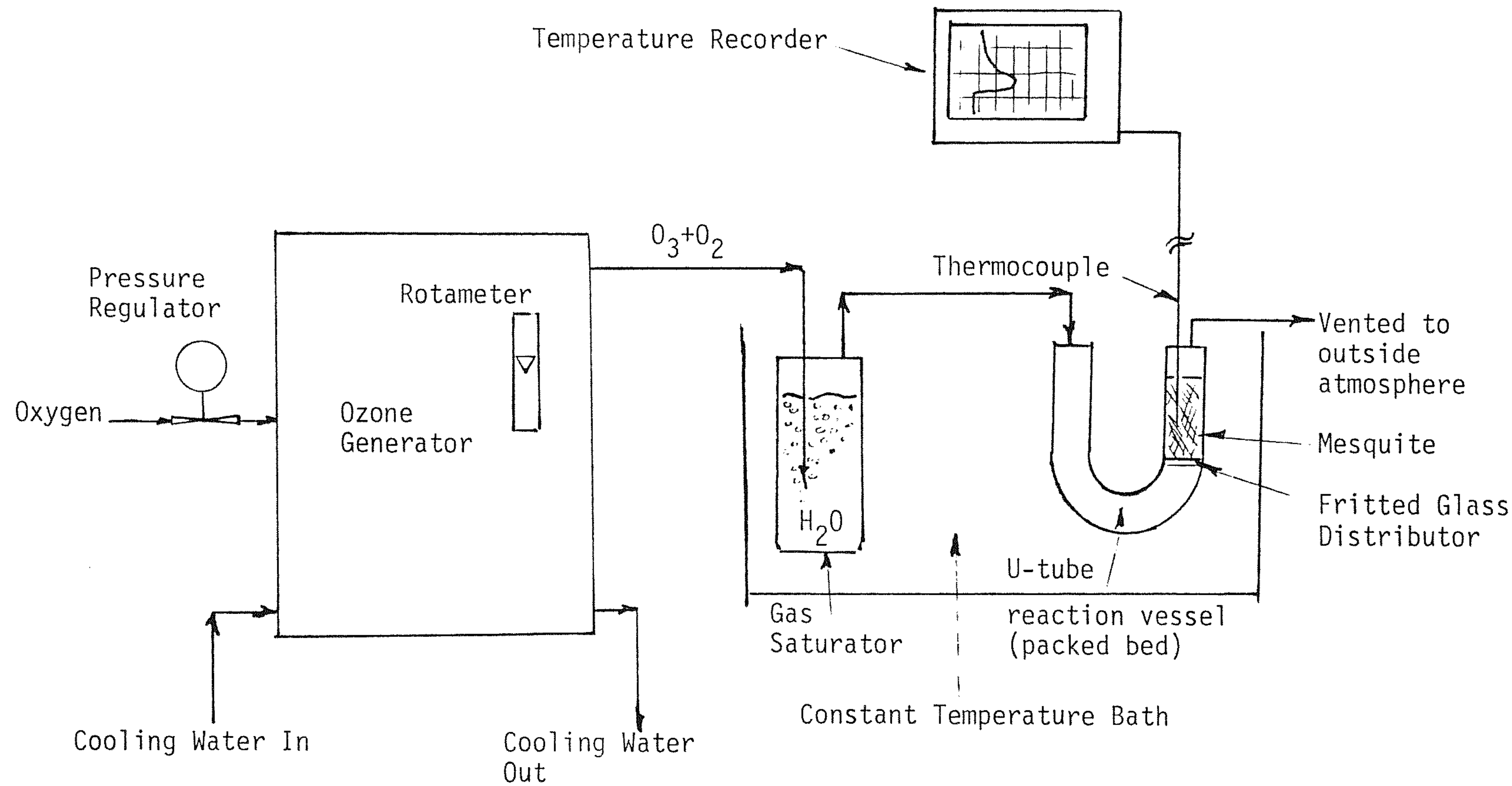

Figure 1. Bench-scale catalyst-ozone-water reaction apparatus (Schematic)

Results

The initial experimentation was designed to determine the effects of various inorganic catalysts on the *in vitro* digestibility of mesquite biomass (60% moisture content) following the use of ozone as the oxidizing agent. The catalysts were chosen because either they have been previously used in wood delignification research, or they had been used as an oxidation catalyst for various other organic reactions. In addition, those cations which were known to have positive stimulatory effects on the rumen bacteria were screened (Church, 1976).

In all, seven catalysts were investigated (Table 1). With 26% IVDMD for untreated mesquite and 41% for ozone treated mesquite to be used as the control, the different catalysts were examined. Vanadium pentoxide increased the digestibility for each increase in concentration. However, its low level for toxic concentrations (5 ppm) was interpreted as being indicative of a reaction which produces soluble products but is not actually degraded by digestive processes by the rumen bacteria. Cupric oxide increased the digestibility slightly at lower concentrations, but decreased the IVDMD level at concentrations in excess of 100 ppm. This may indicate that poisoning of the rumen bacteria may have occurred. Ferric oxide produced results in the range of those produced by ozone treatment alone. Manganese sulfate increased the digestibility by about 12% at the lower concentrations (<100 ppm) with a slightly less pronounced increase above 100 ppm $MnSO_4$. Rubidium chloride showed a significant increase in the digestibility with approximately a 16% increase. The digestibility appeared to be independent of the catalyst concentration. Strontium chloride also increased the digestibility. An increase of about 10% was noted. The digestibility obtained also appears to be independent of $SrCl_2$ concentration. The final catalysts studied was molybdenum trioxide. The results show that an increase (up to 58% IVDMD) can be obtained. Since molybdenum has a high (>500 ppm) toxic concentration, a relatively high(10-200 ppm) stimulatory effect, and produced favorable digestibility results, it was chosen as the catalyst to be used in ther remaining experiments. The effects of various other process conditions on the digestibility using molybdenum were studied by varying the molybdenum concentration in untreated mesquite. As the catalyst concentration increased the digestibility increased (Table 2). This indicates that the molybdenum is very stimulatory. When only oxygen was introduced, however, there was no noticeable effect on the digestibility.

The next series of experiments was designed to determine the effects of various acids on the digestibility. Throughout the next experiments a 400 ppm MoO_3 catalyst concentration was used as a base. The first acid studied was acetic acid. The results tend to indicate a slight inhibiting effect by the acid as compared to the 400 ppm MoO_3 sample. The digestibility increased with increases in acid concentration up to a 3:4 acetic acid to water ratio. For a 1:1 $CH_3COOH:H_2O$ the digestibility decreased. This may be due to the acid concentration being higher than the rumen bacteria can tolerate.

Nitric acid was studied next. The digestibility increased with an increase in the acid/water ratio, but comparing the results with those obtained for the catalyst alone there appears to be an inhibiting effect by the acid. The acid appears to be hydrolyzing some of the components in the wood structure.

Hydrochloric acid also increased the IVDMD with acid concentration increase with the exception of the 1:1 ratio. This value was lower indicating potential poisoning by the acid. As was the case with nitric acid the results are lower than that obtained for only the catalyst at the lower acid concentration. The HCl also appears to be chemically destroying portions of the wood.

The sulfuric acid yielded the most promising results. The general trend for these samples was an increase in digestibility with acid concentration increase. A value of 71% IVDMD was obtained for a 1:1 acid/water mixture. This value also supports the theory the acid is degrading a portion of the wood components. The results also indicate that the catalyst has an effect on the IVDMD. This could be due to a co-catalytic effect by the MoO_3 and the H_2SO_4. Table 3 tabulates the results obtained from the acid studies.

When the time of ozone contact was varied, a maximum IVDMD was obtained at 2 hours. For a contact time greater than 2 hours a decrease occurred with a gradual increase for extended ozone contact. One reason for this trend could be due to the formation or liberation and then the subsequent destruction of inhibiting chemicals. Table 4 lists the results obtained.

Three different particle sizes were investigated (10, 24, and 40 mesh). The highest digestibility was obtained (Table 5) for the smallest particle size (largest surface area per unit mass). This suggests that the surface reaction is the major contributor to the digestibility increase and that diffusion probably limits the level of digestibility achieved in the large particles.

When the initial reactor temperature was varied, the results point to lower temperatures for maximum digestibility (Table 6). For a sample which initially was at 100°C, the ozone-oxygen mixture spontaneously ignited causing the wood to burn. For the three samples studied, the sample which was initially at 0°C yielded the highest IVDMD.

Conclusions

From the results of this study is appears that the molybdenum or rubidium catalysts make a significant improvement in the digestibility of mesquite biomass. The remaining catalysts (iron, copper, vanadium, manganese, and strontium) have a lessor positive effect. For the conditions used in this study (40 mesh particles, 50 ppm O_3) the optimum ozone contacting time is 2 hours. The best initial temperature studied was 0°C. Acids also increased the digestibility (solubility) of the treated mesquite biomass. Sulfuric acid had the greatest effect. Nitric acid and hydrochloric acid also produced increases in the IVDMD. Acetic acid appears to increase the IVDMD less than the other acids, with some inhibiting effects noticeable.

Further investigations on the use of inorganic catalysts should continue with additional work performed to determine the effects of various anions. The effects of the inorganic catalysts studied on the lignin and holocellulose content should also be examined.

Acknowledgement

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LITERATURE CITED

Albin, R. C., Sherrod, L. B., Summers, C. B., Texas Tech Series AS: 77-5 Rep. No. 27, Lubbock, Texas, 1976.

Baker, A. J., Millet, M. A., Satter, R. D., Cellul. Tech. Res., 1975, 6, 75-105.

Chang, J., Master's Thesis, Texas Tech University, Lubbock, Texas, 1981.

Church, D. C., Digestive Physiology and Nutrition of Ruminants, Volume 1: Digestive Physiology, 2nd Edition, Portland, Oregon, Metropolitan Printing Co., 1976.

Fahle, D. W., M. S. Thesis, Texas Tech University, Lubbock, Texas, 1978.

Parker, H. W., Albin R. C., Vernor, T. E., Fahle, D. W, "Thermochemical Modification of Mesquite for Ruminant Rations," Second Pacific Chemical Engineering Conference, Denver, CO, 1977.

Tock, R. W., Richardson, C. R., Gancarz, I., Chang, J., Owsley, M. R., "Ruminant Rations from Mesquite Biomass Pretreated with Water and Ozone," I&EC Prod. Res. Dev., 21, 101-106, 1982.

Vernor, T. E., M. S. Thesis, Texas Tech University, Lubbock, Texas, 1977.

OZONE-TREATED MESQUITE AS THE ROUGHAGE BASE IN RANGE CATTLE SUPPLEMENTAL FEED[1/] [2/]

Fred C. Bryant, Thomas Mills, John S, Pitts, and Mike Carrigan[3/]

Abstract.--Ozoned-mesquite was compared with cottonseed hulls as the fiber base in supplemental rations fed to growing steers under range conditions. Over two winter feeding periods, there was no difference (P 0.05) between average daily gain of steers fed either supplement. Ozoned mesquite should be satisfactory fiber component in supplemental rations fed to range cattle.

INTRODUCTION

Mesquite (*Prosopis glandulosa*) is a rangeland pest that has infested millions of acres in the arid southwest. Attempts to control this woody perennial have included mechanical, pyric, biological, and chemical means. It has only recently been realized that wood from this plant may be an untapped reservoir for industrial uses and livestock feed sources. If harvest and processing becomes economical, all potential avenues for disposal of the lignocellulosic biomass from mesquite should be investigated.

Lignocellulosic residues, including wood pulp, have been the focus of livestock feeding experiments for many years. Research has dealt with corn and milo residues (Bolsen et al. 1977, Ward 1978, Wheeler et al. 1979), cereal and grass straws (Swingle and Waymack 1977, Anderson 1978, Acock et al. 1979, Durham and Hinman 1979, Church and Champe 1980), soybean residues (Miller et al. 1979), cotton by-products (Arndt et al. 1980), and wood and wood by-products (Dinius and Bond 1975, Gharib et al. 1975, Lemiux and Wilson 1979, Seymour and Kamstra 1980).

1/ Paper presented at the Mesquite Utilization Symposium, Texas Tech University, Lubbock, TX, October 29-30, 1982.
2/ This research was supported in part by line item funds provided by the Texas Legislature entitled "Research in Mesquite Utilization." Mention of a trademark or company does not exclude other equipment, trademarks, or companies which also may be suitable.
3/ At the time of this research, Bryant was Assistant Professor, Mills and Pitts were student assistants, and Carrigan was graduate assistant, Department of Range and Wildlife, Texas Tech University, Lubbock, TX 79409.

Many chemical treatments have been applied to increase cellulose digestibility. Some of them included sodium hydroxide (Hendrix and Karn 1976, Acock et al. 1979), calcium hydroxide (Paterson et al. 1979a) and ammonia (Paterson et al, 1979b) on crop residues and sodium hydroxide (Millett et al. 1970), sulfur dioxide (Sherrod et al. 1978), sulphuric acid (Keith and Daniels 1976), irradiation (Kitts et al. 1969), and ozonization (Schuerch 1963) on wood and wood by-products. Ozonization of mesquite appears to have potential of increasing cellulose digestion (R. W. Tock, unpublished data; Weakly and Owens 1975).

While most research has been limited to trials _in vitro_ or _in vivo_ with confined animals in drylot, few studies have attempted to evaluate crop or wood residues in supplemental rations for livestock on dry perennial rangeland. Vavra et al. (1975) and Phillips and Vavra (1977) successfully fed grass straws as a roughage source to wintering range cows in Oregon. The objective of this study was to compare ozoned-mesquite with cottonseed hulls as the fiber base in supplemental rations for growing range steers.

METHODS AND MATERIALS

Whole mesquite trees (2.5 m tall) were mechanically harvested with the Texas Tech University Brush Combine No. IV from rangeland on the Texas Tech Campus during the summer of 1980. The combine reduced the entire above-ground plant to 1.2-1.5 cm chips. Chips, after air-drying 7-9 da to a moisture content of 5-10%, were hammermilled through 6 mm screen. The mesquite meal was ozoned in a continuous stirred tank reactor for 2 hrs. Ozonization was accomplished by adding 60% water, by volume, to approximately 45 lb of mesquite meal in the reactor and passing O_3 through the mixture. Evidently, water swells the wood lumen allowing O_3 access to the lignin before attacking the holocelluloses. After ozonization, the meal was dried in a forced-air oven at 60°C for 12 hrs.

Rations were formulated to provide 25%, by weight, of the fiber base comprised of either cottonseed hulls (control ration) or ozoned-mesquite (mesquite ration) (Table 1). Nutrient balancing, particularly crude protein, was accomplished by adding more or less cottonseed meal or sorghum grain (Tables 1 and 2).

Table 1. Ingredients (%) used rations fed to steers as a supplement to range forage.

Ingredient	Control	Mesquite
Sorghum	47.2	43.2
Fiber	25.0[1/]	25.0[2/]
Cottonseed meal	16.0	20.0
Nutri-binder[3/]	10.0	10.0
Calcium carbonate	0.8	0.8
Sodium sulphate	0.5	0.5
Trace mineral	0.5	0.5
Vitamins[4/]	+	+

1/ cottonseed hulls
2/ processed mesquite pulp
3/ protein (8%), fat (2%), crude fiber (3%), ash (3%)
4/ vitamin A (50 g/ton @ 60,000 u/g), vitamin D (1.75 lb/ton @ 200,000 u/lb), vitamin E (30 g/ton @ 125,000 u/lb)

Table 2. Nutrient and mineral analysis of control and mesquite rations fed to steers as a supplement to range forage.

Nutrient	1980-81		1981-82	
	Control	Mesquite	Control	Mesquite
Crude protein (%)	16.2	14.8	15.0	14.3
Crude fat (%)	2.2	1.9	1.9	2.9
Crude fiber (%)	36.0	40.0	-	-
NFE (%)	25.3	29.4	69.0	66.5
Ash (%)	2.6	3.6	4.6	4.4
TDN(%)	42.5	44.0	70.6	69.9
Sulfur (%)	0.26	0.24	0.41	0.45
Phosphorous (%)	0.32	0.30	0.37	0.41
Potassium (%)	1.36	0.90	1.24	0.55
Magnesium (%)	0.39	0.36	0.29	0.25
Calcium (%)	0.41	0.46	0.57	0.33
Sodium (%)	0.04	0.01	0.14	0.18
Iron (ppm)	150	200	130	120
Aluminum (ppm)	100	130	80	80
Manganese (ppm)	29	39	48	45
Copper (ppm)	15	14	13	8
Zinc (ppm)	32	40	26	32

Individual steer grazing 200 ac of buffalograss (*Buchloe dactyloides*) - blue grama (*Bouteloua gracilis*) range were supplemented using a Calan Broadbent feeding system[1/]. Each steer wore an electronic key that allowed them access to only one feed bin. In the winter feeding period of 1980-81 (January through March), 8 steers received the control ration and an equal number received the mesquite ration at a supplemental rate of 4 lb/day. During the winter period of 1981-82 (November through March), 7 steers were supplemented with the mesquite ration and 6 received the control ration. These steers were started at a daily rate of 2 lb/day in November, adjusted 4 lb/day on December 23, 1981, and increased to 8 lb/day on February 5, 1982, through the end of the feeding period in March, 1982. The latter increase was because of a shortage of native forage. During both winter feeding trials, steers were supplemented every 3 days. Steers weights were recorded monthly.

RESULTS AND DISCUSSION

Average daily gain (ADG) of steers supplemented with the mesquite ration was the same (P 0.05) as steers receiving the control ration when averaged over two winter feeding periods (Table 3). During 1980-81, monthly ADG and mean ADG was the same (P 0.05) for steers receiving either supplement.

In the winter feeding period of 1981-82, ADG of steers supplemented with mesquite was higher (P 0.05) than the control during November and January, but lower (P 0.05) in February and March. The mean ADG for 1981-82 was the same (P 0.05) regardless of ration fed.

1/ American Calan Inc., Route 4, Northwood, NH 03261.

Table 3. Average daily gain (lb/day) of steers supplemented under range conditions with mesquite and control rations.

Ration	1980-81			1981-82					
	Feb.	Mar.	Mean	Nov.	Dec.	Jan.	Feb.	Mar.	Mean
Mesquite	0.45[a]	0.26[a]	0.36[a]	0.91[a]	0.74[a]	1.28[a]	-0.68[a]	0.28[a]	0.51[a]
Control	0.48[a]	0.28[a]	0.38[a]	0.67[b]	0.79[a]	0.61[b]	-0.15[b]	0.59[b]	0.50[a]

[a] Means in the same column with the same superscript are not different (P 0,05).

The lower performance of steers on the mesquite ration in late winter of 1981-82 indicates more supplement should be fed when native forage is in short supply. If forage supply is adequate and a higher level of performance is desired, rations could be mixed to supply more crude protein.

Ozone-mesquite may be a satisfactory fiber base in supplemental rations fed to range cattle. This would be especially true if cattle are in a non-productive physiological status.

Literature Cited

Acock, C. W., J. K. Ward, I. G. Rush and T. J. Klopfenstein. 1979. Wheat straw and sodium hydroxide treatment in beef cow rations. J. Anim. Sci., 49:354-360.

Anderson, D. C. 1978. Use of cereal residues in beef cattle production systems. J. Anim. Sci. 46:849-861.

Arndt, D. L., C. R. Richardon, R. C. Albin and L. B. Sherrod. 1980. Digestibility of chemically treated cotton plant by-product and effect on mineral balance, urine, volume and pH., J. Anim. Sci. 51:215-223.

Bolsen, K. K., C. Grimes and J. G. Riley. 1977. Milo stover in rations for heifers and lambs. J. Anim. Sci. 45:377-384.

Church, D. C. and K. A. Champe. 1980. Digestibility of untreated and hydroxide-treated annual ryegrass straw. J. Anim. Sci. 51:20-24.

Dinius, D. A. and J. Bond. 1975. Digestibility, ruminal parameters, and growth by cattle fed a waste pulp. J. Anim. Sci. 41:629-634.

Durham, R. R. and D. D. Hinman. 1979. Digestibility and utilization of bluegrass straw harvested on three different dates. J. Anim. Sci. 48:464-467.

Gharib, F. H., J. C. Meiske, R. D. Goodrich and A. M. El Serafy. 1975. In vitro evaluation of chemically-treated poplar bark. J. Anim. Sci. 40:734-742.

Hendrix, K. S. and P H. Karn. 1976. NaOH treatment of ensiled and dry corn residue. J. Anim. Sci. 43:325 (Abstract).

Keith, E. A. and L. B. Daniels. 1976. Acid or alkali-treated hardwood sawdust as a feed for cattle. J. Anim. Sci. 42:888-891.
Kitts, W. D., C. R. Krishnamurti, J. A. Shelford and J. G. Huffman. 1969. Use of wood and woody by-products as a source of energy in beef cattle rations. Advances in Chemistry Series No. 95:279-297.
Lemieux, P. G. and L. L. Wilson. 1979. Nutritive evaluation of a waste wood pulp in diets for finishing lambs. J. Anim. Sci. 49:342-353.
Miller, B. L., G. C. Fahey, Jr., R. B. Rindsig, L. L. Berger and W. G. Bottje. 1979. In vitro and in vivo evaluations of soybean residues ensiled with various additives. J. Animal. Sci. 49:1545-1551.
Millett, M. A., A. J. Baker, W. C. Feist, R. W. Mellenberger and L. D. Satter. 1970. Modifying wood to increase its in vitro digestibility. J. Anim. Sci. 31:781-788.
Paterson, J. A., T. J. Klopfenstein and R. A. Britton. 1979a. Ammonia treatment of corn plant residue. J. Anim. Sci. 48 (suppl.):270 (Abstract).
Paterson, J. A., T. J. Klopfenstein and R. A. Britton. 1979b. The interaction of calcium hydroxide treatment and moisture level of crop residues. J. Anim. Sci. 48 (suppl.):270-271 (Abstract).
Phillips, R. L. and M. Vavra. 1977. The evaluation of fescue straw as straw as a roughage source for wintering cows. J. Anim. Sci. 45 (suppl.):353 (Abstract).
Schuerch, C. 1963. Ozonization of cellulose and wood. J. Polymer Sci. Part C, No. 2:79-95.
Sherrod, L. B., C. B. Summers, T. E. Vernor, R. C. Albin and H. W. Parker. 1978. Mesquite for Ruminants. II. Effect of sulfur dioxide treatment upon in vitro digestibility. Texas Tech Univ. Beef Res. Rep. p. 118-138.
Swingle, R. S. and L. B. Waymack. 1977. Digestibility by steers of grain sorghum stover and wheat straw supplemented with NPN. J. Anim. Sci. 44:112-117.
Seymour, J. and Kamstra, L. D. 1979. Whole aspen tree silage as wintering feeds for breed stock cows. S. D. Acad. Sci. 58:157-171.
Vavra, M., R. L. Phillips and J. A. B. McArthur. 1975. Feeding grass straw to wintering cows. J. Anim. Sci. 41:424 (Abstract).
Ward, J. K. 1978. Utilization of corn and grain sorghum residues in beef cow forage systems. J. Anim. Sci. 46:831-840.
Weakley, D. C. and F. N. Owens. 1975. Ozone delignification. J. Anim. Sci. 41:425 (Abstract).
Wheeler, W. E., D. A. Dinius and J. B. Coombe. 1979. Digestibility, rate of digestion, and ruminoreticulum parameters of beef steers fed low quality roughages. J. Anim. Sci. 49:1357-1363.

EVALUATION OF MESQUITE FOR RUMINANTS-EFFECT OF CHEMICAL PRE-TREATMENTS ON IN VITRO DRY MATTER DIGESTIBILITY[3,4]

C. R. Richardson[1], L. D. Bunting[1] and M. R. Owsley[2]

Abstract. Experiments were conducted to determine the effects of biological fermentation, sulfur dioxide (SO_2) treatment, and ozone (O_3) treatment on in vitro digestibility of ground mesquite wood. Various fermentation processes were evaluated for improving in vitro utilization of mesquite, with yeast fermentation of H_2SO_4 treated mesquite having the largest improvement in digestibility, increasing digestibility from 29.3% for controls to 79.9% for treated mesquite. Ground mesquite was treated with SO_2 at different temperatures, reaction times, and concentrations to evaluate effects of various treatments upon in vitro digestibility. Maximum improvement occurred at 6% SO_2 and a reaction temperature of 150° C for 2 h. In vitro dry matter disappearance increased 33% for controls to 68% with SO_2 treatment. Mesquite was contacted with O_3 (50 ppm) in a cylindrical glass gas saturator fitted with a fritted glass bottom. In vitro dry matter digestibility was increased from 30 to 55% by O_3 treatment.

INTRODUCTION

Mesquite thrives on several million acres of range land throughout Texas. The high cost of eradication of this noxious hardwood can be partially offset through utilization of harvested mesquite biomass. Once mesquite has been harvested and ground, it may be used as an alternative roughage source for ruminants. However, the nutritive value of raw mesquite is relatively low, and its value to the ruminant as a feed is somewhat limited without some sort of pretreatment prior to feeding. Studies by Albin, et al. (1977) have shown that the digestibility of mesquite can be improved with chemical treatment. Ozone and sulfur dioxide are two chemical treatments which have been shown to be effective in improving the nutritive value of low quality roughages (Weakley and Owens, 1975; Baker and Millett, 1975). Biological pre-fermentation has also been demonstrated to effectively improve the in vitro digestibility of highly lignified products. The purpose of these investigations was to determine the effect of ozone, sulfur dioxide and biological pre-fermentation on the in vitro digestibility of ground mesquite.

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[3]Presented at the Mesquite Utilization Symposium, Texas Tech University, October 28 and 29, 1982.

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EXPERIMENTAL PROCEDURE

Treatment of Mesquite

Ozone Treatment

Mesquite, ground through a .63 cm screen, was placed in a cylindrical glass gas saturator fitted with a fritted glass bottom, and contacted with ozone enriched oxygen (50 ppm ozone). Contacting time, temperature, and water content of mesquite was varied to determine optimum contacting conditions. Once the mesquite meal had been contacted, it was dried to a moisture content of less than 10% to prevent spoilage.

Sulfur Dioxide Treatment

Mesquite was ground through a .6 mm screen and treated with various concentrations of sulfur dioxide added as sulfurous acid at different temperatures and times in a teflon lined acid digestion bomb. These bombs were fastened to a device which slowly tumbled them end-over-end to obtain mixing a reduce time required to reach the desired temperature. Treatment descriptions are included in table 2.

Biological Fermentation

Mesquite was ground through a .6 mm screen and treated with either sodium hydroxide or sulfuric acid prior to being incubated with yeast cultures, a pure bacterial culture, mixed bacterial cultures, and combinations of bacterial and yeast cultures. A strain of bacteria of the psuedomonas species (JM-127), known to degrade cellulosic materials, was used as a pure bacterial culture. Treatments used in mesquite prefermentations are given in table 3.

In Vitro Determinations

In vitro digestibility of all treatments was determined by the Moore modification of the two-stage Tilley-Terry procedure (Harris, 1970), which was further modified by using 2.0 g samples and 100 ml rumen fluid: buffer solution (30:70) inoculum in 250 ml centrifuge bottles. Dry matter residues were corrected for residue blanks. Treated samples were corrected for residue ash above that contained in the original samples prior to calculation of dry matter digestibility. Organic matter digestibility was calculated from the dry matter residues following ashing.

RESULTS AND DISCUSSION

The in vitro dry matter digestibilities of mesquite treated with ozone at varying reaction times and temperatures are given in table 1. The higher digestibilities occur at the longer reaction times and lower temperatures, with the greatest improvement in digestibility occurring after 5 h of reaction of 0^oC.

The digestibility of mesquite treated with sulfur dioxide under varying conditions is given in table 2. Treatment appears to have a greater affect at smaller particle sizes. Treatment also appears to take place more rapidly at elevated temperatures and increased pressure. A sulfur dioxide concentration of 6% also appears to give greater improvement in mesquite digestibility.

Table 3 gives the in vitro digestibility of mesquite pre-fermented by various fermentative processes. Digestibility appears to be depressed by most treatments, however, the combination of JM127 and yeast fermentation of H_2SO_4 treated mesquite gives promising results.

TABLE 1. PERCENT IN VITRO DRY MATTER DIGESTIBILITY OF MESQUITE TREATED WITH OZONE AT DIFFERING CONTACT TIMES AND TEMPERATURES

	Temperature[a]	
Contact time (h)	0° C	25° C
0	33.0	...
.5	45.0	31.0
1.0	50.0	...
2.0	55.0	42.0
5.0	57.5	43.5

[a]In vitro dry matter digestibility.

TABLE 2. IN VITRO ORGANIC MATTER DIGESTIBILITY OF SULFUR DIOXIDE TREATED MESQUITE

Treatment	Particle size (mm)	Reaction time (h)[a]		
		.5	1.0	2.0
3% SO_2; 150°C	.6	35.1	41.0	36.2
6% SO_2; 150°C	9.5	15.4	25.7	17.6
6% SO_2; 150°C	.6	40.2	44.6	37.0
6% SO_2; 170°C	.6	30.8	49.0	38.4
6% SO_2; 150°C 30 P.s.i.g.	9.5	19.2	33.9	35.6
6% SO_2; 150°C 30 p.s.i.g.	.6	...	60.7	68.0

[a]In vitro dry matter digestibility.

TABLE 3. EFFECT OF BIOLOGICAL PRE-FERMENTATION ON THE IN VITRO DRY MATTER AND ORGANIC MATTER DIGESTIBILITY OF GROUND MESQUITE

Fermentation process	IVDMD[a]	IVOMD[b]
Control-ball milled mesquite	29.7	28.2
Mixed culture bacteria	18.7	17.0
JM127 fermentation	18.2	17.4
JM127 and yeast fermentation of H_2SO_4 treated mesquite	79.9	79.5
JM127 and yeast fermentation of 4% NaOH neutralized mesquite	23.8	23.9
JM127 fermentation of 4% neutralized mesquite	10.4	9.8

[a]In vitro dry matter digestibility.

[b]In vitro organic matter digestibility.

LITERATURE CITED

Albin, R. C., T. E. Vernor, H. W. Parker, L. B. Sherrod and C. B. Summers. 1977. Mesquite for ruminants. I. Effects of thermochemical treatment upon in vitro digestibility. Texas Tech University Center Res. Rep. 27:22

Baker, A. J. and M. A. Millett. 1975. Wood and wood-based residues in animal feeds. Cellulose Tech. Res. 6:75.

Harris, L. E. 1970. Nutrition Research Techniques for Domestic and Wild Animals. Vol. I. Published by L. E. Harris, Logan, Utah.

Marion, R. D., C. E. Fisher and E. D. Robison. 1957. Ground mesquite wood as a roughage in rations for yearling steers. TX. Agr. Exp. Sta. Prog. Rep., 1972, cattle series 141.

Weakley, D. C. and F. N. Owens. 1975. Ozone delignification. J. Anim. Sci. 41:425.

OZONE AND SULFUR DIOXIDE TREATED MESQUITE AS A FEED FOR RUMINANTS[4,5]

C. R. Richardson[1], L. D. Bunting[1], M. R. Owsley[2] and D. B. McCarthy[3]

Abstract. Four experiments were conducted to evaluate the utilization, nitrogen retention and digestibility of sulfur dioxide (SO_2) and ozone (O_3) treated ground mesquite. SO_2 treatment was accomplished by treating 50% dry matter, shredded mesquite with 6% SO_2 vapor at 150° C and 30 p. s. i. for 2 h. Ozone treatment was achieved by treating 40% dry matter mesquite with 50 ppm ozone for 2 h at 0 C. An 85 day metabolism trial was conducted with 5 lambs, with treatments being A) 100% practical diet, B) 90% practical + 10% SO_2 treated mesquite, C) 80% practical diet + 20% SO_2 treated mesquite, D) 60% practical diet + 40% SO_2 treated mesquite, E) 60% practical diet + 40% untreated mesquite. Apparent DMD for treatments were 73.94, 70.06, 63.17, 53.89, and 60.75 respectively. A second 85 day metabolism trial was conducted with five lambs, with untreated or SO_2 treated comprising either 10 or 20% of complete diets. The apparent DMD for both the 10 and 20% treated mesquite and the 20% untreated were less than the control ($P < .01$), while the 10% untreated was not different ($P > .01$) from the control. A feedlot study was conducted with growing lambs with SO_2 treated mesquite supplemented at graded levels. Treatments included a control (75% concentrate, 25% cottonseed hulls) and 3 diets of SO_2 treated mesquite making up 5, 10 or 20% of the cottonseed hulls. Lambs consuming the control, 5, 10 or 20% treated mesquite had similar gains and feed conversion ($P > .05$) with the exception of the 20% treated mesquite diet, which had depressed feed conversion. An additional metabolism trial was conducted with growing lambs in which untreated, SO_2 treated or O_3 treated mesquite replaced 10% of the cottonseed hulls in a basal diet (75% concentrate, 25% cottonseed hulls). No differences ($P > .05$) were noted in dry matter digestibilities across treatments.

INTRODUCTION

Experiments have been conducted since 1938 in an effort to develop effective methods for controlling and eradicating mesquite which infests about 70 million acres of grassland in the United States. Research has shown that harvested mesquite may be successfully incorporated into ruminant rations (Marion, et al., 1957). However, the low available energy content of raw mesquite has limited its feeding value to that of a bulk factor. The energy

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availability of mesquite can be improved with chemical treatment (Albin, 1977). Ozone and sulfur dioxide are two chemical treatments which have been demonstrated to be effective in improving the feeding value of low quality roughages (Weakley and Owens, 1975; Baker and Millett, 1975). The purpose of these studies was to determine the feeding value of ozone and sulfur dioxide treated mesquite.

EXPERIMENTAL PROCEDURE

SO_2 Treatment of Mesquite

Mesquite was shredded in a grinder with a 6.3 mm screen, resulting in a shredded particle with the smallest dimension being .5 mm. Water was added in a ratio of 1:1 ground mesquite (GM) to water. The GM was then sealed in a cylindrical vessel reactor and 6% SO_2 vapor was added to the cylinder. An operating temperature of 150°C was employed at 30 p.s.i. pressure for a period of 2 h. After reaction, the GM was then neutralized with the addition of ammonium hydroxide and air dried.

O_3 Treatment of Mesquite

Mesquite was shredded in a grinder with a 6.3 mm screen. Ground mesquite was treated with ozone in a continuously stirred batch reactor (.05 M^3), with an ozone-oxygen mixture introduced at 8 standard liters per minute with an ozone concentration of 50 ppm. Only ambient temperatures were used, and no provision was made to remove the heat of reaction. After desired contacting time was achieved, the material was dried to 6% moisture in a forced air dryer.

Experiment 1

Five wether lambs were used in an 85 day metabolism study, with total feces and urine collection. A 5 x 5 Latin square design was used with each period consisting of 7 days of collection preceded by 14 days of adjustment. Water was provided ad libitum. Treatments used were as follows: A) 100% practical diet (75% concentrate, 25% cottonseed hulls); B) 90% practical diet + 10% SO_2 treated mesquite; C) 80% practical diet + 20% SO_2 treated mesquite; D) 60% practical diet + 40% SO_2 treated mesquite; E) 60% practical diet + 40% untreated mesquite.

Experiment 2

Five wether lambs were used in an 85 day metabolism study, with total feces and urine collection. A 5 x 5 Latin square design was used with each period consisting of 7 days of collection preceded by 14 days of adjustment. Water was provided ad libitum. Lambs were fed equally during collection. Treatments used were as follows: A) 100% practical diet (75% concentrate + 25% cottonseed hulls); B) 90% practical diet + 10% SO_2 treated mesquite; C) 90% practical diet + 10% untreated mesquite; D) 80% practical diet + 20% SO_2 treated mesquite; E) 80% practical diet + 20% untreated mesquite.

Experiment 3

Forty-eight growing lambs averaging 30.5 kg were used in a 56-day feeding study. Lambs were stratified by initial weight and sex across four treatments. Data were analyzed as a completely randomized design. Lambs were weighted at 28-day intervals and feed consumption was recorded. A 75% concentrate diet in which graded levels of SO_2 treated mesquite replaced cottonseed hulls was furnished ad libitum in self feeders. The four treatments were: A) control; B) 5% SO_2 treated mesquite; C) 10% SO_2 treated mesquite; D) 20% SO_2 treated mesquite. Twelve lambs were allotted to each of four treatments with two replications per treatment, and six lambs per replication. Response criteria were average daily gain and feed efficiency.

Experiment 4

Ten lambs were used in a 5 x 5 Latin square design with total collection of feces and urine. Test periods consisted of 7-day collections preceded by 10-day adaptation periods. Water was furnished ad libitum. Treatments were as follows: A) control diet (75% concentrate + 25% cottonseed hulls); B) 90% control diet + 10% SO_2 treatment mesquite; C) 90% control diet + 10% ozone treated mesquite; D) 90% control diet + 10% untreated mesquite.

RESULTS AND DISCUSSION

Apparent digestibilities and nitrogen retentions for experiments 1 and 2 are given in tables 1 and 2, respectively. Data from both metabolism trials appear to indicate that SO_2 treatment did not significantly improve the digestibility of GM. Dietary levels of SO_2 treated mesquite greater than 10% appear to depress dry matter digestibility. Performance data from the feeding study (table 3) indicate that substitution of either treated or untreated mesquite in the diet had no affect on ADG of lambs. Higher levels of SO_2 treated mesquite appeared to lower feed to gain ratio for lambs, however.

Dry matter digestibilities for diets A, B, C, and D, for experiment 4 were 65.3, 62.1, 65.6 and 63.8, respectively. No differences ($P > .05$) were noted between treatments, although the ozone treated mesquite appeared to be slightly higher than the untreated mesquite.

It would appear from these studies that SO_2 and O_3 treated mesquite can be successfully incorporated into ruminant rations, however it is not clear if the treatments actually improve the feeding value of mesquite.

TABLE 1. COMPOSITION, IN VIVO DIGESTIBILITY AND NITROGEN RETENTION OF DIETS CONTAINING SULFUR DIOXIDE TREATED OR UNTREATED GROUND MESQUITE (GM) - EXP. 1

Item	Diet				
	Control 0 % GM	10 % GM Treated	20 % GM Treated	40 % GM Treated	40 % GM Treated
Composition, %[a]					
Dry Matter	88.63	86.47	84.76	81.09	90.21
Crude protein	12.09	12.81	13.67	15.33	10.56
Ash	6.39	6.23	6.35	5.31	5.73
Digestibility,%					
Dry matter	73.94[b]	70.06[b]	63.16[c]	53.89[d]	60.75[c]
Organic matter	73.85[b]	70.95[b]	64.67[c]	55.35[d]	62.03[c]
Nitrogen retention					
Percent of intake	31.87[b]	24.60[b]	15.41[bc]	12.27[c]	19.41[bc]
Grams/day	3.81[b]	3.04[b]	1.97[bc]	.87[c]	1.93[bc]

[a]All values except dry matter are expressed on a dry matter basis.

[b,c,d]Means in the same row followed by different superscripts differ ($P < .01$).

TABLE 2. COMPOSITION, IN VIVO DIGESTIBILITY AND NITROGEN RETENTION OF DIETS CONTAINING SULFUR DIOXIDE TREATED OR UNTREATED GROUND MESQUITE (GM) - EXP. 2

	Diet				
Item	Control 0 % GM	10 % GM Treated	10 % GM Untreated	20 % GM Treated	20 % GM Untreated
Composition, %[a]					
Dry matter	88.63	86.47	88.80	84.76	89.33
Crude protein	12.09	12.81	11.48	13.62	11.09
Ash	6.39	6.23	6.60	6.35	6.72
Digestibility, %					
Dry matter	74.83[b]	70.41[cde]	71.51[bd]	66.27[ce]	69.22[cde]
Organic matter	74.74[b]	71.30[cde]	73.01[bd]	67.73[ce]	70.50[cde]
Nitrogen retention					
Percent of intake	27.57[b]	24.57[b]	27.56[b]	19.16[b]	28.91[b]
Grams/day	3.21[b]	2.78[b]	3.15[b]	2.49[b]	3.21[b]

[a]All values except dry matter are expressed on a dry matter basis.

[b,c,d,e]Means in the same row followed by different superscripts differ ($P < .01$).

TABLE 3. PERFORMANCE OF LAMBS CONSUMING DIETS CONTAINING SULFUR DIOXIDE TREATED GROUND MESQUITE (GM) - EXP. 3

	Diet			
Variable	Control 0 % GM	5 % GM Treated	10 % GM Treated	20 % GM Treated
No. per treatment	12	12	12	12
Initial weight, kg	30.5	30.5	30.6	30.6
Final weight, kg	38.8	39.8	40.0	38.7
Daily gain, kg	$.149^{a} \pm .004$[1]	$.165^{a} \pm .012$	$.164^{a} \pm .033$	$.145^{a} \pm .001$
Daily feed, kg	$1.19^{a} \pm .080$	$1.47^{ab} \pm .260$	$1.20^{a} \pm .120$	$1.68^{b} \pm .200$
Feed/gain ratio	$.127^{b} \pm .013$	$.118^{b} \pm .014$	$.135^{b} \pm .014$	$.088^{c} \pm .011$

[a,b,c]Means in the same row followed by different superscripts differ ($P < .05$).

[1]Mean ± SE for 12 animals.

LITERATURE CITED

Albin, R. C., T. E. Vernor, H. W. Parker, L. B. Sherrod and C. B. Summers. 1977. Mesquite for ruminants. I. Effects of thermo-chemical treatment upon in vitro digestibility. Texas Tech University Center Res. Rep. 27:22.

Baker, A. J. and M. A. Millett. 1975. Wood and wood-based residues in animal feeds. Cellulose Tech. Res. 6:75.

Marion, R. D., C. E. Fisher and E. D. Robison. 1957. Ground mesquite wood as a roughage in rations for yearling steers. TX. Agr. Exp. Sta. Prog. Rep., 1972, cattle series 141.

Weakley, D. C. and F. N. Owens. 1975. Ozone delignification. J. Anim. Sci. 41:425.

SOME ECONOMIC CONSIDERATIONS ON THE USE OF MESQUITE IN RUMINANT RATIONS[1]

Richard Wm. Tock[2]

[3]For the ruminant animal, the holocellulose contained in mesquite biomass represents a potential food source. It is estimated that seventy percent of the mass of air dried, mesquite-wood is theoretically digestible. However, research has shown that this level of utilization is seldom achieved in practice unless the biomass is chemically treated. Such chemical processing adds significantly to the cost of using mesquite as a ruminant ration. Moreover, there have been no large scale studies on the *in vivo* effectiveness of chemically treated mesquite as a ration. This makes comparisons with standard rations on a cost effectiveness basis difficult to perform. Even so, an attempt will be made in this paper to explore some of the economic constraints placed on the use of mesquite biomass as a ruminant ration. Correlations will be drawn with respect to alfalfa which is comparable to treated mesquite in digestibility and for which price information is available. Some comparisons will also be made with the higher priced feed grains. Based on these data it appears as though mesquite derived rations can compete as a roughage in animal diets. However, only under unusual economic conditions will it ever be used as more than a temporary maintenance ration.

INTRODUCTION

Historically, waste-wood biomass has been viewed as a potential, low-grade feedstock for ruminant animals (Baker, et al., 1975). Laboratory tests have indicated that woody materials contain from 65% to 70% holocellulose (Scott, et al., 1969). It is this cellulose fraction which hypothetically can be converted by the rumen microflora into a biological energy source. This level of utilization is seldom achieved, however, outside the laboratory. For example, biomass derived from mesquite by harvesting the entire above ground structure has an *in vitro*

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[1]Paper presented at the first symposium on mesquite utilization. (Texas Tech University, Lubbock, Texas, October, 1982).
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digestibility of only twenty-six percent (Tock, et al., 1982). This low level of conversion (roughly one third of what is available) precludes any realistic use of raw mesquite as a feed ration. Investigations have shown that the low conversion levels can be attributed to the shielding effects of the lignin fraction of the wood, and, to a lesser extent, to natural digestion inhibitors secreted by the living tree as protection from microbial attack. If either or both of these barriers could be removed, then the full seventy percent of the woody mass is potentially available for conversion. This would mean that rations prepared from mesquite could have a food value in the range of hay and other roughages in the ruminant diet. Hence, it could provide an alternate or substitute ration for stockmen.

Unfortunately, the removal of the shielding effects of the lignin in wood and the chemical inhibitors is not easily accomplished. Fish, (1982) reviewed more than thirty publications and presentations by researchers at Texas Tech University dating back to 1968 which dealt with mesquite conversion processes. We will hear some of this technology discussed during this symposium. In most cases the pretreatment processes which were successful involved chemical changes or combined thermal-chemical processing. And while some techniques gave acceptable results in vitro, they were not always successful in small scale in vivo studies. Either the chemical degradation destroyed as much of the cellulose fraction as it did the lignin fraction (thereby reducing the total mass available for conversion), or there were new and perhaps additional inhibitors generated during the chemical treatment.

Even so, the results were encouraging enough in some instances to continue the development of the technology for converting wood residues to animal rations. In fact two patents have been granted for this purpose (U.S. Patent No. 4,136,207 and No. 3,939,286). The Stoke technology described in #4,136,207 uses acetic acid and steam under pressure to rupture the lignin-cellulose bonds. Several commercial installations have been built which utilize softwoods or bagasse wastes. The Jelks process described in #3,939,286 used steam pressure and air with catalysts. This too had several commercial processing plants built to operate on waste biomass; one of which was in Tulia, Texas. Unfortunately, this site was abandoned because of poor economics.

One of the processes developed at Texas Tech University which looked attractive from the standpoint of the quality of feed produced was one which treated the biomass with ozone. This process will be discussed in other sessions of this symposium. Some form of patent protection is still being sought for this technology. While most of the preliminary information remains positive with respect to digestibility levels that can be achieved by this process, there are still many unanswered questions concerning scale-up to commercial production. This is particularly true with respect to the economics. Therefore, this paper will attempt to look at some of the overall economic constraints placed on the chemical conversion of mesquite biomass to a ruminant ration.

ECONOMIC CONSIDERATIONS

The control or comparison parameter to be used in the following discussion will be the level of *in vitro* digestibility for a given material. This approach will be taken in order to reduce the influence of differences produced by test methodologies for *in vivo* studies, and to limit associative effects which are known to arise in animals when several different ingredients are blended to form a feed ration. These effects are discussed by Church (1976) and indicated by his data shown in tables 1 and 2.

Table 1. Digestion Percentages of Feedstuffs by Cattle (Schneider, 1947).

Material Tested	Percent Digestibility, Dry Basis: Organic Matter	Crude Protein	Crude Fiber
Wheat Straw	53	14	58
Hay-Alfalfa	56	61	39
Mixed Grasses	54	23	62
Silage - Alfalfa	60	67	52
Grass	71	60	78
Grains - Barley	81	70	6
Corn	87	75	19
Wheat	88	78	3

Table 2. Percent Digestibility of Corn Silage When Fed With Different Rations (Church, 1969).

Material Tested	Percent Digestibility Dry Basis: Organic Matter	Crude Protein
Alfalfa Pellets	57	71
Steer Finishing Ration	77	73
Alfalfa & Corn Silage	68	73
Finishing Ration Corn Silage	70	69
Estimated Digestibility of corn silage when fed with:		
alfalfa pellets	80	75
finishing ration	61	62

These data indicate that there can be considerable variation in the digestibility levels of even established rations. However, we will assume some general averages for purposes of comparison. These values will then be used throughout the study. They are given in table 3.

Table 3. Average Percent Digestibility For Materials Used in This Study.

Material	Percent O.M. Digestibility	Mass Ratio Relative to Corn
Raw Mesquite	25	3.48
O_3-Treated Mesquite	41	2.12
O_3-Catalyst-Treated Mesquite	58	1.5
Alfalfa	56	1.55
Corn	87	1.0

From table 3 it is obvious that feed grains represent a more concentrated form of nutrition than the other materials listed. As shown by the last column, ruminant livestock would need to ingest nearly three and one half times as much raw mesquite as they would corn in order to receive the same level of nutritional value. On the other hand, ozone treated mesquite is essentially on a par with alfalfa with respect to food value. Hence, alfalfa and O_3 treated mesquite can be used interchangeably in mixing rations, without any loss or sacrifice in nutrition. On an economic basis, therefore, mesquite which has been upgraded by chemical treatment for a ruminant ration, will be competing on a one-to-one price ratio with alfalfa. If it costs more to produce a ton of treated mesquite than the market price of alfalfa, then there is little econmic incentive to harvest and treat mesquite.

Figure 1, shows the daily cash price quotations for alfalfa pellets on a quarterly basis as reported in the Wall Street Journal. Similar plots can be prepared for any feed grain commodity. The average price of alfalfa pellets over the seven year period is approximately $88/ton. The maximum was $115/ton and the minimum $54/ton. The trend in maximum price levels shows a 1.5 percent increase per year while the minimum have a 8.2 percent yearly increase for the period of 1976 to 1983. These figures generally reflect the inflation pattern during this seven year period. Also seasonal drought conditions coincide with some of the peak prices.

Using this information on alfalfa prices and some estimated costs of harvesting and chemical treatment for mesquite, some breakeven levels for treated mesquite as a substitute for alfalfa can be generated. The general expression can be written in the following manner.

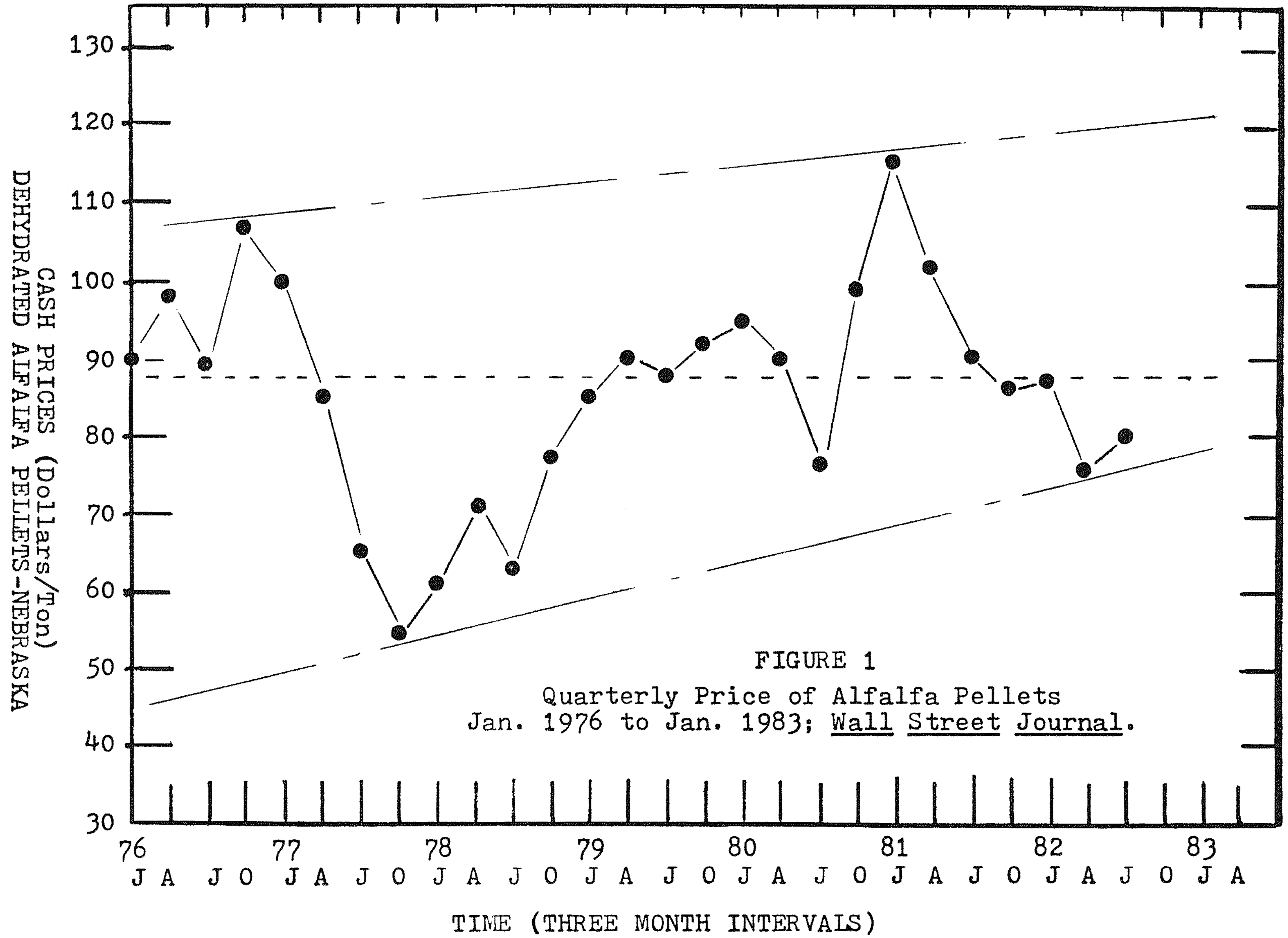

FIGURE 1

Quarterly Price of Alfalfa Pellets
Jan. 1976 to Jan. 1983; Wall Street Journal.

$$CPT = K_F(CTH + CCP)$$

CPT is the cost per ton of ration
K_F is the coefficient for digestibility relative to corn
CTH is the cost for harvesting and mechanical processing in dolalrs per ton
CCP is the cost for chemical processing in dollars per ton.

Cauble (1978) estimated the cost of delivered mesquite wood chips to be \$6.09 per ton of dry weight. This figure was based on a 500 ton per day harvesting operation. With this figure and an average inflation rate of 8% per year the present cost to harvest and process (CTH) is approximately \$9.00 per ton dry weight.

Chang (1981) and later Fish (1982) estimated the cost of chemically treating mesquite with ozone-water and catalysts. Their figures were based on a 30,000 head cattle operation. Without catalyst the cost came to \$95/ton dry weight. Depending on the amount of catalyst used the increase in cost reached approximately \$100/ton. Using these values, the cost per ton (CPT) was calculated for various grades of mesquite. These are shown in table 4.

Table 4. (CPT) Cost Per Ton of Treated Mesquite Having a Digestibility (*in vitro*) Equivalence of Corn.

Material	KF	CTH ton	CCP ton	CPT	ECBC*
Raw Mesquite	3.48	\$9.00	---	\$31.32	\$0.90
O_3-Treated Mesquite	2.12	\$9.00	\$95.00	\$220.48	\$6.20
O_3-Treated Mesquite plus Catalyst	1.5	\$9.00	\$100.00	\$163.50	\$4.60
Alfalfa Pellets	1.55	---	\$88.00 ($\pm$ \$30.00)	\$136.40	\$3.80

*ECBC - Equivalent cost of a bushel of corn.

The information in table 4, while preliminary, indicates the price levels at which the various feed rations can compete with corn. The CPT column indicates the price per ton while the last column (ECBC) puts the price on a basis of dollars per bushel of corn equivalence. Since the current cash price of corn is approximately \$2.60-\$3.00 per bushel only the raw mesquite is competitive. This is misleading in that there are some real questions as to whether the ruminant animal could or would ingest enough raw mesquite biomass to sustain itself. Alfalfa and mesquite biomass treated with O_3 and catalysts both come closest to competing with present corn prices. Certainly if feed grains were to increase sharply in price because of major crop failures, then either would represent an alternative feed material capable of sustaining an animal herd. The choice between the use of alfalfa or mesquite in a mixed ration is not discernible from table 4. At the highest price levels of $115 per ton for alfalfa, mesquite is most certainly a viable substitute. However, this price level is seldom reached and sustained for protracted periods of time, and a large scale venture into chemically treated mesquite for ruminant rations alone would most certainly be doomed to failure.

Cox (1982) investigated the use of ozone treated mesquite biomass as a source of cellulose for fuel grade ethanol synthesis. Here again it was shown that the woody biomass materials cannot compete with the feed grains and sugar crops as a source of alcohol. Chen (1981) looked at the extractables from mesquite biomass and found some unique flavanoids in the heartwood. These were not economically recoverable, however, and other studies have shown that mesquite as a source of wood products and chemicals just is not practical. Mesquite is two dispersed, slow growing, and of too knarled a configuration to compete in the forest products industry.

One attractive feature of mesquite harvest and utilization as a ruminant ration, however, is that the harvesting permits immediate regrowth and grazing of native grasses. Spraying of mesquite infested pastures usually requires removal of livestock from affected areas for finite periods of time. Mechanical harvesting would not require such and the exposed grasses would benefit from increases of usable sunlight and moisture. In fact turn over times would probably be comparable to fire control technology; the big difference is that fire requires very little capital investment.

CONCLUSIONS

Studies have shown that chemically treated mesquite can compete with alfalfa on a nutritional level. However, only under unusual circumstances will it be competitive with alfalfa on an economic basis. Hence the use of mesquite in ruminant rations for feedlot operations probably is not feasible. For a large ranching operation where the harvesting process returns the pastures to better grass production and the harvested mesquite is used as a substitute for alfalfa or a similar roughage, then the economics may be positive.

LITERATURE CITED

Baker, Andrew J., Millett, M. A. and Satter, L. D., Wood and Wood-Based Residues in Animal Feeds. Cellulose Technology Research, ACS Symp. Series No. 10, 1975 pp. 75-105.

Bender, Robert (Stake Tech. Ltd.) U.S. Patent No. 4,136,207.
Cauble, Douglas Glenn, "A Cost Analysis of Alternative Methods of Mesquite Harvesting," M.S. Thesis, Texas Tech University, Lubbock, Texas 1978.
Chang, J., "Comparison of Mesquite Thermal Chemical Treatment for a Ruminant Ration," M.S. Thesis, Texas Tech University, Lubbock, Texas, 1981.
Chen, Shou-Jen R., "Extraction of Organic Chemicals From Mesquite," M.S. Thesis, Texas Tech University, Lubbock, Texas, 1981.
Church, D. C., Digestive Physiology and Nutrition of Ruminants, Volume 1: Digestive Physiology, 2nd Ed., Portland, Oregon, Metropolitan Printing Co., 1976.
Cox, K. W., "Selected Methods Utilizing Ozone for Hydrolysis of Mesquite Biomass," M.S. Thesis, Texas Tech University, Lubbock, Texas, 1982.
Fish, S. J., "Increasing the In Vitro Digestibility of Mesquite With Inorganic Catalysts and Ozone," M.S. Thesis, Texas Tech University, Lubbock, Texas, 1982.
Jelks, J. W., U.S. Patent No. 3,939,286.
Schneider, B.H., Feeds of the World, W. Virginia Agr. Expt. Sta., 1947.
Scott, R. W., Millett, M. A., and Hajny, W., "Wood Wastes for Animal Feeding," Forest Products Journal, 19(4), 1969, p. 14-18.
Tock, Richard Wm., et al., "Ruminant Rations from Mesquite Biomass Pretreated With Water and Ozone," I&EC Prod. Res. & Dev., 21, 1982, 101-106.
Wall Street Journal, Selected Issues, 1976-1983, "Cash Prices."

NUTRITIONAL VALUE OF MESQUITE BEANS

(*Prosopis glandulosa*)[1,2]

Reza Zolfaghari and Margarette Harden[3]

Abstract.--Proximate composition of green and mature mesquite fruit varied slightly. The protein content of seed is similar to that of soybean but higher than other legumes. Mesquite beans are deficient in the sulfur containing amino acids but did support partial growth of weanling rats. Addition of 0.3% methionine to the seed diets resulted in only minor improvement. According to chemical analyses, the beans are good sources of Ca, Mg, K, Fe and Zn.

INTRODUCTION

As the world population increases to six billion by the year 2000, the demand for food will escalate. Legumes are an economical source of calories and protein. Sinha (1977) wrote "There are some legumes of great potential that have not yet been fully developed or utilized for food or feed. One is the pods and seeds of the desert mesquite." Mesquite now occupies 70 million acres of ranchland in the Southwest of the United States (Smith and Rechenthin, 1964; Goldstein et al., 1971) and is constantly expanding. This figure represents 50% of the grasslands in the state of Texas.

The honey mesquite (*Prosopis glandulosa*) a leguminous shrub or tree was considered a valuable plant by the Indians, Mexicans and pioneers during the 1800s and early 1900s. The mesquite beans provided man, wild game and livestock with food (Schuster, 1969). The mesquite beans with their leaves while succulent were eaten by cattle during the spring and early summer (Walton, 1923). The immature mesquite pods were boiled and eaten by Indians and the ripe pods were ground to make different kinds of food (Palmer, 1871; Forbes, 1895; Gard, 1954; Simpson, 1977).

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Walton (1923) reported that one acre of land covered with mesquite trees could produce 100 bushels of fruit per year. Thus mesquite represents a significant amount of energy that need not be wasted. Many methods of controlling and eliminating mesquite growth have been used, however, fewer attempts have been made to utilize it. Since the mesquite grows well in arid and semi-arid lands, use of bean might be of nutritive value as food for man. The economically attractive utilization would be to harvest and process the mesquite for feed and food.

The literature contains little information about the nutritive value of the green and mature mesquite beans (P. glandulosa), especially for human beings. This project was initiated: (1) to investigate the nutrient composition of the intact green and mature mesquite bean pods (fruits) and of the separated seed and pericarp; and (2) to determine the biological value of the raw and processed mature seed.

MATERIALS AND METHODS

Sample Preparation

Honey mesquite fruits in both green and mature stages grown without pesticide or irrigation control were collected from the Department of Range and Wildlife Management experimental station, Texas Tech University, Lubbock, Texas. The harvested green mature fruits were sealed separately in plastic bags and stored in a freezer at -18°C.

Mature pods, free from insect damage, were hand separated into the two fractions, seed and pericarp. The proportion of each fraction was determined. Seed, pericarp, green and mature fruit after freeze drying were finely ground into a flour with a Thomas-Wiley Laboratory Mill. For chemical analysis, the flour, placed in small jars was stored in the freezer (-18°C) in a desiccator under vacuum.

For the animal study, the freeze-dried mature fruit were milled in a sheller to separate the seed. The Thomas-Wiley mill was used to grind the cleaned seed into flour. For the heat treated sample, the flour in 10 mm layers was autoclaved at 121°C for 15 min, lyophilized and reground into a fine meal. Both the raw and the autoclaved samples were sealed in separate plastic bags and stored in the freezer (-18°C) for analysis.

Chemical Analysis

Proximate analysis of the freeze-dried samples was performed according to AOAC (1975) procedures. Moisture was determined by drying under vacuum at 100°C, lipid content by extraction with petroleum ether on Soxhlet's apparatus, crude protein by Macro-Kjeldahl (using N x 6.25 factor), ash content by ashing at 550°C in a Muffle furnace and crude fiber of defatted samples by digestion. The digestible carbohydrate was calculated by difference.

For amino acid composition, the samples hydrolyzed under vacuum and nitrogen flush in 6NHCl at 110^{o}C for 22 hrs were separated and determined using a Beckman Model 116 Amino Acid Analyzer. Methionine and cysteine (1/2 cystine) were determined after pre-treatment of samples with performic acid and hydrolyzing under vacuum with 6NHCl at 105^{o}C for 24 hrs (Lewis, 1966). Tryptophan was determined by hydrolyzing the samples in alkaline solution (Pon et al., 1970).

Trypsin inhibitor activity of all the samples, raw and heat treated, was determined by the method of Kakade et al. (1974). One gram of ground sample was extracted with 50ml of 0.01NNaOH. The suspension was diluted to the point where 2ml produced trypsin inhibition of 40-60%. Bovine trypsin was used to hydrolyze the synthetic substrate, N-benzoyl-DL-arginine-p-nitroanilide (BAPA) hydrochloride for trypsin activity study. One trypsin unit was arbitarily defined as an increase of 0.01 absorbance units at 410mm per 10ml of the reaction mixture under the given condition. Trypsin inhibitor activity was expressed in terms of trypsin units inhibited (TIU).

Phytate content of the samples was analyzed by the ion exchange chromatographic method of Harland and Oberleas (1977) with a slight modification of the extraction of phytate from the seed samples. Due to the stickness of the extract the ratio of the seed sample to 1.2% HCl solution was reduced from 1:20 to 1:40.

Individual minerals, Ca, Mg, Fe, Zn, Cu, Mn and Co, were analyzed by atomic absorption spectroscopy by Perkin Elmer Corp. methods (1973). K was measured by the atomic absorption spectroscopic method of Hills et al. (1982). The wet digested samples were diluted with cesium chloride solution (4mM) before spectrophotometric analysis. Na was determined by flame photometry. The flameless atomic absorption spectroscopy of both Cr and Se was determined according to the methods described by Kumpulainen et al. (1974) and Dillon et al. (1982), respectively. Total phosphorous was determined by the colorimetric method of Summer (1944).

Rat Feeding Experiment

Mesquite seed diets were fed at a 10% protein level. Vitamin free casein at the 10% protein level was used as the reference protein diet. Diets were adjusted to 4% mineral content (Jones and Foster Salts), 5% fibre (nonnutritive fibre), 5% fat (corn oil) and 1% vitamin mix. Cerelose was added to 100%. Twenty-one day old weanling male albino rats of the Sprague Dawley strain originally weighing 40-45g were individually housed in screen bottomed cages. All of the rats were given standard purina rat chow for 5 days prior to feeding the experimental diets. Seven rats were assigned to each diet for the 28 days to estimate protein efficiency ratio (PER). An extra group of 7 rats were fed a nonprotein diet for the first 10 days of the experimental period and the average weight loss used for determination of net protein ratio (NPR). Food and water were given ad libitum. The temperature of the experimental room was kept constant between 21-23^{o}C during the assay period. Food intakes and weights of rats were measured weekly. During the last week (21-28 day) of the experimental period the food intake and fecal output were recorded daily to determine the apparent digestibility of protein. Feces of each rat were collected daily, dried at room temperature and stored frozen for N analysis. The feces were ground and analyzed for N by Macro-Kjeldahl. The apparent digestibility of protein was calculated by the following formula: Apparent digestibility of protein = $\frac{\text{N intake(g) - N fecal(g)}}{\text{N intake}} \times 100$.

RESULTS AND DISCUSSION

The proportion of seed to pericarp fraction(W:W) of the honey mesquite fruit (P. glandulosa) was 14.95:85.05. This is similar to the mechanically separated value determined by Becker and Grosjean (1980) for this species. The seed yield in honey mesquite is significantly lower than that of velvet mesquite (P. velutina), which was estimated by these authors. This may be due to either the differences in moisture content of the pericarp of velvet mesquite or to agronomical conditions (Becker and Grosjean, 1980). In this study, as it was impossible to separate the seed from the green pod, the whole green fruit was used for all analyses.

The proximate composition of the mesquite bean samples is shown in table 1. The moisture contents of both the green and mature fruit were over 50% and less than 10%, respectively (data not shown). Except for indigestible fiber (crude fiber) no difference existed in the proximate composition of green and mature fruit on the dry weight basis (table 1).

Table 1.--Proximate composition of mesquite beans.

Sample	Components (% on dry weight basis)				
	Protein (n x 6.25)	Crude fat	Ash	Crude fiber	Total carbohydrate
Green fruit	13.26	2.23	3.88	35.33	80.63
Mature fruit	13.35	2.87	3.40	24.73	80.38
Seed	39.34	4.91	3.61	6.86	52.14
Pericarp	7.02	2.08	3.62	29.63	87.08

The crude fiber contents of green and mature fruit were 35% and 25%, respectively. In contrast to mature fruit which tasted sweet, the green fruit was tart and slightly bitter. Walton (1923) found no significant difference in proximate composition between slightly immature and fully mature fruit, and he reported a slightly higher sugar content in the fruit just before maturity.

While most of the protein of mature fruit is in the seed, total carbohydrate primarily accumulates in the pericarp portion (table 1). Protein content of the mesquite seed is similar to that of soybean varieties and is higher than the 20-22% protein content of common legumes. Although the protein content of the pericarp portion is low (7%), the value is comparable to common cereal grains such as barley and rice (Pomeranz, 1978). The pericarp fraction contains about 30% crude fiber which is five times more than that in the seed. Of the digestible carbohydrate fraction, no starch was detected in any of the mesquite bean samples by glucose oxidase enzyme system. Other researchers have also reported the absence of starch in other mesquite bean species (Walton, 1923; Jones and Earle, 1966; Earle and Jones, 1962; Becker and Grosjean, 1980).

Comparison of the essential amino acid FAO (1973) reference pattern to the mesquite bean samples (table 2) shows that the sulfur-containing amino acids are the first limiting. This has been observed in most dry legumes (FAO, 1970). With exception of relatively lower values for aspartic acid and proline, the data for other amino acids of green fruit protein are somewhat similar to those of mature fruit protein. When comparing to the FAO pattern, the pericarp contains slightly more of some of the essential amino acids than the seed. In addition to the limiting sulfur containing amino acids, the seed protein is deficient in both threonine and tryptophan. However, as would be expected, the so-called storage amino acid, arginine, is much higher in the seed than in the pericarp protein. Exclusion of this amino acid from the diet of growing animal has been reported to reduce weight gain (Rose, 1937).

Similar to most dry beans and peas, mesquite bean contains antinutritional factors such as trypsin inhibitor. Trypsin inhibitor activity of mesquite seed was 5.8 TIU per mg of dry sample. This was less than half of the value of a black eyed bean variety determined in this laboratory. Autoclaving of the seed for 15 min lowered the trypsin inhibitor activity by over 33%. Trypsin inhibitor contents of the green and mature fruit were 1.94 and 1.29 TIU per mg dry sample, respectively. Trypsin inhibitor was also detected in the pericarp portion of mesquite bean (0.77 TIU/mg dry sample).

Table 2.--Amino acid composition of mesquite beans.

Amino acid (g/16 g N)	Sample				FAO[1] reference
	Green fruit	Mature fruit	Seed	Pericarp	
Non-essential Amino Acids					
Alanine	4.91	4.49	5.00	4.34	
Arginine	8.84	7.57	14.53	2.96	
Aspartic acid	13.61	19.32	9.75	24.24	
Glutamic acid	15.69	14.00	22.29	8.66	
Glycine	5.63	4.36	5.61	4.00	
Histidine	2.98	2.46	2.98	2.17	
Proline	6.22	9.70	5.73	12.17	
Serine	3.98	3.46	3.31	3.79	
Essential Amino Acids					
Isoleucine	3.84	3.27	3.24	3.39	4.00
Leucine	7.97	8.71	7.74	10.43	7.00
Lysine	6.67	5.45	5.16	6.00	5.50
Cysteine (Cys)	0.79	1.30	1.41	0.66	
Methionine (Met)	0.65	0.72	1.07	0.67	
Cys + Met	1.44	2.02	2.48	1.33	3.50
Phenylalanine (Phe)	4.26	3.60	4.28	3.17	
Tyrosine (Tyr)	2.06	1.80	2.04	2.15	
Phe + Try	6.32	5.40	6.32	5.32	6.00
Threonine	3.66	3.53	3.00	4.23	4.00
Tryptophan	0.99	0.76	0.75	0.89	1.00
Valine	5.66	5.92	4.40	7.61	5.00

[1]FAO, 1973.

Results of the PER and NPR study showed that mesquite seeds provided nitrogen not only for body maintenance but also for partial growth of weanling rats (table 3). The PER value for rats fed the raw seed diet was about 32% of the value for the reference casein diet. This could be related to inadequate quantities of some of the essential amino acids of the seed protein such as the sulfur-containing ones (table 2). However, addition of methionine to both raw and autoclaved seed diets only slightly improved the PER value (table 3). Poor response to the added methionine probably could be due to: (1) the limitation of some other essential amino acids such as threonine or tryptophan (table 2) and (2) the deficiency of some micronutrient or the presence of unknown factors which inhibit the biological use of an essential nutrient by the test organism. The amino acid composition of one species of mesquite seed (P. africana), reported by FAO (1970), showed a deficiency in threonine, valine and isoleucine not in methionine. Tryptophan and cysteine assays were not reported for this species of mesquite bean.

Table 3.--Biological evaluation of mesquite seed with and without methionine supplementation.

Protein diet source	Weight gain (g/day)	Protein efficiency ratio (PER)	Adjusted PER	Net protein ratio (NPR)	Apparent Digestibility (%)
Raw seed	0.84 ± 0.23[a]	0.87 ± 0.24	0.79 ± 0.23	1.50 ± 0.28	70.93 ± 3.07
Cooked seed	1.06 ± 0.27	1.06 ± 0.31	0.97 ± 0.28	1.66 ± 0.32	71.00 ± 1.92
Raw seed + 0.3% methionine	1.07 ± 0.28	1.05 ± 0.18	0.95 ± 0.17	1.61 ± 0.13	69.18 ± 3.36
Cooked seed + 0.3% methionine	1.23 ± 0.38	1.17 ± 0.21	1.08 ± 0.19	1.76 ± 0.16	72.00 ± 3.23
Casein	3.88 ± 0.44	2.75 ± 0.13	2.50	3.17 ± 0.18	93.94 ± 0.87

[a]Mean ± standard deviation.

Also, poor response to methionine supplementation could be due to the addition of an inadequate quantity. Growth response of rats to autoclaved beans supplemented with methionine has been demonstrated to be different depending on bean species or varieties (Evans et al., 1974; Sgarbieri et al., 1979). Sgarbieri et al. (1979) found a good apparent correlation between PER and available methionine in cultivars of dry beans (phaseolus vulgaris, L.). They showed that the lower the PER in the beans, the lower the availability of added methionine.

Heat treatment of seed appears to be necessary although PER of the autoclaved sample was improved by only 22% (table 3). This may be due to either low heating time (15 min) or inappropriateness of the cooking method used in this study since only one-third of trypsin inhibitor content was reduced. However, Borchers and Ackerson (1950) were unable to show any correlation between improvement in nutritive value as determined by growth data after autoclaving and the presence or absence of trypsin inhibitor in the raw legume seeds.

Apparent digestibilities of 70-72% were found for the mesquite seed protein as compared to 94% for the reference casein (table 3). Digestibility of mesquite seed protein is somewhat lower than reported for some common dry beans and peas (Hove et al., 1978) but it is still higher than for some cultivars of dry beans (Sgarbieri et al., 1979). Autoclaving for 15 min did not seem to improve digestibility of the mesquite seed protein since only one-third of trypsin inhibitor content of raw seed was reduced during the heat treatment. However, the trypsin inhibitor content of mesquite seed is far below the value of soybean (KaKade et al., 1974) which could interfere with the digestibility of protein. Jaffe' (1950) demonstrated that autoclaving increased digestibility of those legume seeds with higher initial trypsin inhibitor activity such as soybean.

Protein quality of mesquite seed as shown by PER (table 3) is within the range of 0.5-1.5 reported for most legumes (Aykroyd and Doughty, 1964). The relative low digestibility of mesquite seed protein compared with some common beans may be attributed to the presence of either significant amount of heat stable storage protein, namely globulin (Seidl et al., 1969; Jaffe', 1950) or some non-adventitious factors such as metal binding factors as mentioned by Rockland and Radke (1981). Unlike other common beans such as lima and navy beans (Friedman, 1975; Hove et al., 1978) raw mesquite seed apparently does not contain any toxic matter which could result in the death of animals. Becker and Grosjean (1980) found no cyanogenic compounds in honey mesquite beans by either Kronig reaction or the picric acid test which gave positive results for lima bean samples.

Table 4 shows that Ca, Mg, total p, phytate p, K and Na contents of green fruit are similar to those of mature fruit. While most of the Ca, K and Na are concentrated in the pericarp portion of the mature fruit, Mg, total p and phytate p are mostly accumulated in the seed (table 4). With the exception of Na which is comparatively lower, all other macro-mineral contents of the seed are close to those values reported by Becker and Grosjean (1980) for this species of mesquite bean. Lower Na content of the samples may be due to the low Na concentration of the Lubbock county soil (Zartman, 1981)[4]. However, the Na concentration of mesquite bean determined in this study is comparable to that reported for common beans and peas (Meiners et al., 1976; McCarthy et al., 1977; Augustin et al., 1981; Sankara and Deosthale, 1981).

Table 4.--Macro-element concentration of mesquite beans.

Sample	Element (mg/100 g dry weight)					
	Ca	Mg	Total p	Phytate p	K	Na
Green fruit	530	120	110	44	1560	9.1
Mature fruit	430	90	130	46	1495	8.2
Seed	260	210	310	282	865	7.2
Pericarp	440	80	80	6.7	2150	10.4

Like most legumes, mesquite seed is considerably richer in Ca than most common cereals (Pomeranz, 1978). More than 90% of the total p in seed is in the form of phytate which is equivalent to 1%. This value is lower than that of soybean products (Thompson and Erdman, 1982). Very small portions of total p in the pericarp (0.023% dry weight basis) was detected as phytate. Ca/P ratios of mesquite bean samples ranged from 0.84 for seed to 5.5 for pericarp.

Raw legumes are usually high in K. In this respect, mesquite seed is not exceptional. K/Na ratios in all samples of mesquite bean are considerably high.

The concentrations of trace minerals of mesquite bean samples are shown in table 5. Except for Mn and Cr, the values for each individual trace mineral of green fruit are somewhat similar to those of mature fruit. Mn and Cr contents of green fruit are almost double the values for mature fruit. Unlike Se, the other trace minerals are much higher in the seed than in the pericarp portion of mature fruit.

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[4] Zartman, Richard E. 1981. Personal communication, Department of Plant and Soil Science, Texas Tech University, Lubbock, Texas.

Table 5.--Trace element concentration of mesquite beans.

Sample	Trace element (μg/g dry weight)						
	Fe	Zn	Cu	Mn	Co	Se	Cr
Green fruit	42	26	6.74	20.06	0.66	2.72	0.19
Mature fruit	31	26	7.71	11.40	0.78	3.31	0.08
Seed	156	108	17.24	27.80	1.26	0.59	0.19
Pericarp	15	19	6.55	9.95	0.58	3.92	0.09

Fe and Zn contents of mesquite bean samples determined in this study study are relatively higher than reported in the literature (Pak et al., 1977; Becker and Grosjean, 1980). While concentrations of Fe and Zn are higher, Cu, Mn and Cr of the seed are close or within the range of those values reported for common beans and peas (Meiners et al., 1976; McCarthy et al., 1977; Augustin et al., 1981; Sankara Rao and Deosthale, 1981). Phytate to Zn molar ratios vary widely among mesquite bean samples (table 4 and 5). The ratios ranged from 1.2 for pericarp to 9.2 for seed.

The Se content of mesquite seed is comparable to values of pea varieties (*Pisum sativum*) as determined by Reichert and Mackenzie (1982). The Se concentration of pericarp portion is more than 6 times of that in the seed. Apparently, whole mesquite beans are rich in Se. This could be due to the Se content of the soil area which is classified as a rich source of Se (Spallholz et al., 1981).

Results of macro- and trace mineral study (table 4 and 5) show that green and mature fruit could provide similar individual mineral contents. While the pericarp portion of mature fruit is richer in Ca and K, the seeds have much higher individual trace mineral contents. None of the mesquite bean samples had a favorable Ca/P ratio which is in the range of 1-2 for rats. Phytate protein complex has been known to interfere with availability of some minerals like Ca, Zn to animals. Simultaneous lower Ca and higher phytate in seed as compared to those of pericarp may cause unavailability of appreciable amount of Ca to animals. Phytate to Zn molar ratios less than 10 have been recommended for the diets of rats (Harland and Oberleas, 1981). None of the individual mesquite bean samples had higher than this ratio. However, high fiber content of the samples other than the seed should not be ignored since higher fiber may interfere as much as phytate in mineral bioavailability.

If availability of iron content of mesquite seed were similar to those of common bean cultivars, (*P. vulgaris, L.*), which were reported to be around 5% to rats (Sgarbieri et al., 1979) mesquite seed would provide about 7 ppm available iron.

CONCLUSION

Mesquite bean is a wild leguminous plant growing in arid and semi-arid lands. The literature contains no report on the yield of its bean production under agricultural management. Although honey mesquite seed is exceptionally high in protein content (about 40%), the seed yield of fruit is relatively low compared to the other species of mesquite reported in the literature (Becker and Grosjean, 1980). If desirable, this could be improved either by growing the plant through proper agronomical conditions or by plant breeding or both. Hand separation of seed from the pod is extremely tedious and time consuming. On the other hand, at this time mechanical separation does not seem logical nor economical because of rigidity of the pericarp portion surrounding the seed.

The pericarp portion of fruit can be a potential source of food for human consumption though it is high in fiber. However, the fiber fraction of pericarp is mostly accumulated on the exocarp and endocarp of the pod. The mesocarp portion mostly contains digestible nutrients including protein. The fiber fraction can be removed by screening after shelling the pod. In this laboratory, the fiber content of pericarp was reduced from 30% to less than 10%. The remaining portion after reduction of fiber constituted about 40% of the fruit and contained more than 8% protein. This helped increase not only the protein content but also could improve the availability of the mineral contents of pericarp. Furthermore, due to the high lysine content of pericarp protein, this portion could be used for protein supplementation of cereal grains.

Like most dry legumes the biological value of mesquite seed as shown by rat growth data was comparatively low. This may be due to deficient quantities of the sulfur containing amino acids as shown by chemical analysis. However, addition of 0.3% methionine to the seed diet did not improve the protein quality of the seed significantly. This may be corrected by either addition of higher levels of this amino acid or with addition of other amino acids such as threonine and tryptophan. Supplementation of the mesquite seed to cereal grains may also improve the protein quality for both legumes and cereals.

Mesquite seed did not exhibit any appreciable amounts of heat-labile trypsin inhibitor which would interfere with protein digestibility of seed. Autoclaving of the seed for 15 min did not significantly improve the protein digestibility. The digestibility of seed protein may be improved by using an appropriate cooking method.

Mesquite bean, like other legumes, is a good source of minerals especially, Ca, Mg, K, Zn and Fe. Further research is needed to determine the mineral bioavailability to animals. Results of chemical study showed that the green fruit is somewhat similar to that of mature fruit in essential nutrient contents. Green fruit had much less insect infestation than mature fruit during harvesting. However, abnormal flavor as well as high fiber content of green fruit may make it difficult to use as is for food without some kind of processing.

Due to the low yield of seed and the problem of seed and the pericarp separation, current research is being conducted to determine if the whole fruit can be used as: (1) a supplementary food product and (2) as a source of dietary fiber for consumption by human beings.

LITERATURE CITED

AOAC. 1975. Official methods of analysis, 12th ed. Association of Official Analytical Chemists, Washington, D.C.

Augustin, J., C.B. Beck, G. Kalbfleish, L.C. Kagel, and R.H. Matthews. 1981. Variation in the vitamin and mineral content of raw and cooked commercial Phaseolus vulgaris classes. J. Food Sci. 46:1701.

Aykroyd, W.R., and J. Doughty. 1964. Legumes in human nutrition. Food and Agriculture Organization, United Nations, Rome, Italy.

Becker, R., and O.K.K. Grosjean. 1980. A compositional study of pods of two varieties of mesquite (Prosopis glandulosa, P. velutina). J. Agric. Food Chem. 28:22.

Borchers, R., and C.W. Ackerson. 1950. The nutritive value of legume seeds. X. Effect of autoclaving and the trypsin inhibitor test for 17 species. J. Nutr. 41:339.

Dillon, L.J., D.C. Hilderbrand, and K.S. Groon. 1982. Flameless atomic absorption determination of selenium in human blood. Atomic Spect. 3:5.

Earle, F.R., and Q. Jones. 1962. Analyses of seed samples from 113 plant families. Econ. Bot. 16:221.

Evans, R.J., D.H. Bauer, K.A. Sisak, and P.A. Ryan. 1974. The availabiltity for the rat of methionine and cystine contained in dry bean seed (Phaseolus vulgaris). J. Agric. Food Chem. 22:130.

FAO. 1970. Amino acid content of foods and biological data on protein. Food and Agriculture Organization, United Nations, Rome, Italy.

FAO. 1973. Energy and protein requirements. Food and Agriculture Organization, United Nations, Rome, Italy.

Forbes, R.H. 1895. The mesquite tree: Its product and uses. Arizona Agr. Exp. Sta. Bull. 13 p. 12.

Friedman, M. 1975. Protein nutritional quality of foods and feeds: Part 2: Quality factors--plant breeding, composition, processing, and antinutrients. Marcel Dekker, Inc., 270 Madison Ave., N.Y., N.Y. 10016.

Gard, W. 1954. Mesquite jungles of Texas. Science Digest 35:5.

Goldstein, I.S., and A. Billarreal. 1971. Chemical composition and accessibility to cellulose of mesquite wood. Wood Science 5:15.

Harland, B.F., and D. Oberleas. 1977. A modified method for phytate analysis using an ion-exchange procedure: Application to textured vegetable proteins. Cereal Chem. 54:827.

Hills, D.L., J.G. Morris, and Q.R. Rogers. 1982. Potassium requirement of kittens as affected by dietary protein. J. Nutr. 112:216.

Hove, E.L., S. King, and G.D. Hill. 1978. Composition, protein quality and toxins of seeds of the grain legumes Glycine max, Lupinus spp., Phaseolus spp., Pisum sativum, and Vicia faba. New Zeal. J. Agric. Res. 21:457.

Jaffé, W.G. 1950. Protein digestibility of trypsin inhibitor activity of legume seeds. Proc. Soc. Exptl. Biol. Med. 75:219.

Jones, G., and F.R. Earle. 1966. Chemical analyses of seeds II: Oil and protein content of 759 species. Econ. Bot. 20:127.

KaKade, M.L., J.J. Rackis, J.E. McGhee, and G. Puski. 1974. Determination of trypsin inhibitor activity of soy products: A collaboration analysis of an improved procedure. Cereal Chem. 51:376.

Kumpulainen, J.T., W.R. Wolf, C. Veillon, and W. Mertz. 1979. Determination of chromium in selected United States diets. J. Agric. Food Chem. 27:490.

Lewis, O.A.M. 1966. Short ion-exchange column method for the estimation of cystine and methionine. Nature 209:1239.

McCarthy, M.A., E.W. Murphy, S.J. Ritchey, and P.C. Washburn. 1977. Mineral content of legumes as related to nutrition labeling. Food Tech. 31(2):86.

Meiners, C.R., N.L. Derise, H.C. Lau, M.C. Crews, S.J. Ritchey, and E.W. Murphy. 1976. The content of nine mineral elements in raw and cooked mature dry legumes. J. Agric. Food Chem. 24:1126.

Oberleas, D., and B.E. Harland. 1981. Phytate content of foods: Effect on dietary zinc bioavailability. J. Am. Diet. Ass. 79:433.

Pak, M., H. Araya, R. Villalon, and M.A. Tagle. 1977. Analytical study of tamarugo (Prosopis tamarugo) and autochthonous Chilean feed. J. Sci. Food Agric. 28:59.

Palmer, E. 1871. Food products of the North American Indians. <u>In</u> U.S. Dept. Agr. Ann. Rep., 410-411 pp.

Perkin-Elmer Corp. 1973. Analytical Methods for Atomic Absorption Spectrophotometry, Norwalk, CT.

Pomeranz, Y. 1978. Cereal '78: Better nutrition for the world's millions. American Ass. of Cereal Chemist, Inc., 3340 Pilot Knob Road, St. Paul, Minnesota 55121.

Pon, N.G., K.D. Schnackerz, M.N. Blackburn, G.C. Chatterjee, and E.A. Noltmann. 1970. Molecular weight and amino acid composition of fine-times crystallized phosphoglucose isomerase from rabbit skeletal muscle. Biochem. 9:1506.

Reichert, R.D., and S.L. Mackenzie. 1982. Composition of peas (Pisum sativum) varying widely in protein content. J. Agric. Food Chem. 30:312.

Rockland, L.B., and T.M. Radke. 1981. Legume protein quality. Food Tech. 35(3):79.

Rose, W.C. 1937. The nutritive significance of the amino acids and certain related compounds. Science 86:298.

Sankara Ras, D.S., and Y.G. Deosthale. 1981. Mineral composition of four Indian food legumes. J. Food Sci. 46:1962.

Schuster, J.L. 1969. Literature on the mesquite (Prosopis L.) of North America. International Center for Arid and Semi-Arid Studies Spec. Rept. 26, Texas Tech Univ., Lubbock, TX.

Seidl, D., M. Jaffé, and W.G. Jaffé. 1969. Digestibility and proteinase inhibitory action of a kidney bean globulin. J. Agric. Food Chem. 17:1318.

Sgarbieri, V.C., P.L. Antunes, and L.D. Almeida. 1979. Nutritional evaluation of four varieties of dry beans (Phaseolus vulgaris, L.). J. Food Sci. 44:1306.

Simpson, B.B. 1977. Mesquite: Its biology in two desert scrub ecosystems. Dowden, Hutchinson & Ross, Inc., Stroudsburg, PA.

Sinha, S.K. 1977. Food legumes: Distribution adaptability and biology of yield. Food and Agriculture Organization, United Nations, Rome, Italy.

Smith, H.N., and C.A. Rechenthin. 1964. Grassland Restoration. The Texas brush problem, U.S. Dept. Agric., Soil Conservation Service.

Spallholz, J.E., J.L. Martin, and H.E. Ganther. 1981. Selenium in biology and Medicine. AVI Publ. Co., Inc., Wesport, CT.

Summer, J.B. 1944. A method for the colorimetric determination of phosphorus. Science 100:413.

Thompson, D.B., and J.W. Erdman. 1982. Phytic acid determination in soybeans. J. Food Sci. 47:513.

Walton, G.P. 1923. A chemical and structural study of mesquite, carob and honey locust beans. U.S. Dept. Agric. Bull., 1194 p.

MILLING AND SEPARATION OF PROSOPIS POD COMPONENTS

AND THEIR APPLICATION IN FOOD PRODUCTS

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A dry-milling and separation process was developed for quantities of up to 500kg/h of Prosopis pods. Fractions of different chemical compositions were produced and their possible application tested in cereal products. The gum fraction was studied and the interaction of the galactomannan with Xanthan determined.

INTRODUCTION

Prosopis pods have been an important natural food resource in arid zones for Indian and African natives over the past centuries. Pater Barzanan reported about the South American Indians (Figueiredo, 1975): "When the rainfall was too little to grow corn and the rivers didn't have enough water for irrigation the Indians did exist almost only on mesquite. It did not only serve as a food but they also brewed a very strong alcohol beverage from the pods and they never had as many fights and deaths as they had during Mesquite harvesting season!"

These original consumers of prosopis pods made two different flour fractions from the fruit. One flour was obtained from the mesocarp and another flour from the true seeds which were separated from the stony endocarp by pounding in bedrock mortars (Felger, 1971).

Very little work has been done so far to replace the bedrock mortar with contemporary technology (Flynt; 1969) in order to produce large quantities of prosopis flour fractions. This paper describes a milling and separation process through which quantities up to 500 kg pods per hour can be processed. Four

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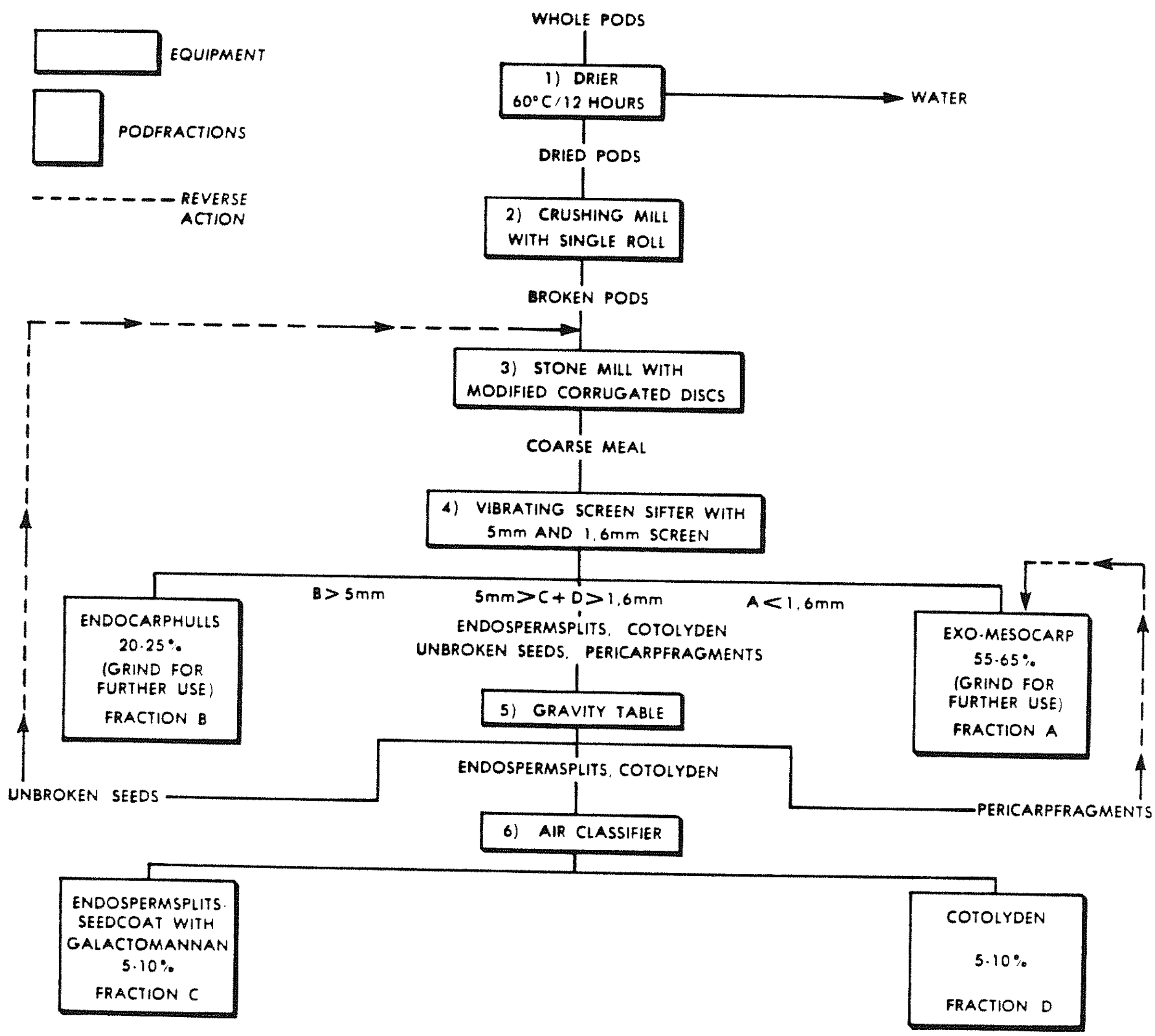
TABLE 1:

MILLING AND SEPARATION PROCESS FOR PROSOPIS PODS



mill fractions are produced, each one rich in certain compounds and being suited for further applications.

This study is part of a larger project at this laboratory to develop the technology to harvest, mill, and find food applications for the whole pod and mill fractions of Prosopis species. The information provided in this paper should therefore be regarded as an intermediate report of an ongoing project.

EXPERIMENTAL

Milling and Separation

Mature Prosopis velutina pods were collected from beneath trees in the Salton Sea area of California and stored frozen to control insect infestations. After some unsuccessful tests on different types of mills the investigation led to use of the milling and separation process shown in Table 1.

Before the pods are milled they must be dried to about 5% H_2O. For this almost any hot air dryer that will maintain at least 60°C for 12 hours is acceptable. The pods must be broken into 2-5 cm pieces with a Buehler-Miag, MBP single roll mill operated at low speed to facilitate feeding into the stone mill. Then a stone mill is used with disks that tear up the endocarp. This is the most critical and difficult milling operation and should only be attempted on thoroughly dry pods. The stone mill is a Buehler-Miag MJSG with modified corrugated disks with a gap of 3.5 mm, shoulder to shoulder, operated at 590 rpm.

The milled pods were separated into the mill fractions using a SWECO Vibrating Screen Sifter. The first SWECO screen had 5 mm square holes which retained the fibrous endocarp hulls (Fraction B). The second screen (1.6 mm diameter round holes) passed the powdery exo-mesocarp material (Fraction A) and retained the seed cotyledon and endosperm-splits (Fraction C+D). The retained material was passed over a Forsberg 10-M-2 gravity table to remove unbroken seeds and bigger exocarp material, which were recycled through the stone mill. The seed coat was separated from the seed gum using wet milling techniques as described later. All fractions can be further milled with common flour mills as desired. (Mention of brand names does not constitute endorsement by the authors in favor of other products that might be equally suitable).

Characterization and Application of the Milling Fractions

All fractions were quantitatively compared with hand-separated samples and analyzed using AOAC (1975) approved methods. Dietary fiber was determined as in Van Soest and Robertson (1977).

Use in bread: Fraction A and B, the two pericarp fractions were substituted for parts of the cereal grain in a standard whole grain flour up to the percentage at which an evident change in taste and/or appearance and/or baking quality occurred. The mixture contained whole grain flour of wheat, barley, and corn, water, salt, and yeast plus the percentage of Prosopis flour.

Doughs were also baked replacing wheat 100% with Prosopis flour.

Use in cookies: A premixed cookie recipe which is sold on the Swiss market (Migros Gersten-Malz biscuits) was adapted to the use of Prosopis flour by replacement of parts of the cereal flours. Both the cookie and the bread were evaluated by a taste panel.

Gum Analysis: 0.5 gm seed coat and seed gum (Fraction C) were ground in a high-speed mill, added to 100 ml distilled water, heated for 4 hours at 80°C, centrifuged, and the supernatant freeze dried. The lyophilized gum was hydrolyzed with trifluoroacetic acid, the aldonitrile acetate derivatives formed, and the component sugars determined by gas chromatography, and the galactose: mannose ratio determined (Stern *et al*, 1969).

To determine the gum viscosity, 5 gm seed coat and seed gum (Fraction C) were allowed to soak in distilled water for two hours. The seed coat was then separated manually and the pure galactomannan freeze dried. From this material a 0.5% solution was prepared and its viscosity determined with the amylograph. The amylograph temperature was started at 25°C then raised to 90°C at 1.5°C/min and lowered back to 25°C at 1.5°C/min. The viscosity was measured with a 500 cmg unit.

The xanthan gum interaction was determined by preparing pure Prosopis gum as above and mixing with xanthan gum (0.25% Prosopis to 0.05% xanthan). The amylograph viscosity was determined using the temperature program described for the pure Prosopis gum with a 250 cmg unit.

RESULTS AND DISCUSSION

The mature pods as collected are very hygroscopic and unless protected from atomospheric moistures will rapidly change from brittle to pliable and sticky. Moist pods are virtually impossible to dry mill; they quickly plug any mill screens and fill abrasive surfaces. However, when dried to 5% moisture or less, the pods are easily milled in such diverse instruments as hammer mills, pin mills, or stone mills, but to produce certain fractions the described stone mill showed the best results.

The stone mill used in our process can be adjusted to give seed fractions as we have in Table 1, or whole seeds, which could be used in reforestation projects. Counter turning roller mills also result in whole seed fractions, but are less satisfactory for milled seeds. Stone milled whole seeds have the advantage of being scarified, which greatly increases the seed hydration and percent germination.

The coarse pod meal from the stone mill is also hygroscopic and should be protected from moisture. The milling process can produce significant exo- and mesocarp dust (Fraction A) which is sugar-rich and can quickly cover everything with a sticky film unless controlled. Vibrating screens create less dust problems than air classification and give an efficient separation of the pericarp fines (Fraction A) and the endocarp hulls (Fraction B).

The gravity table separates the pericarp pieces that accompanied fractions C + D through the SWECO screens. These fractions are now free of dust and conveniently air classified into seedcoat + seed gum and cotyledon fractions C and D, respectively.

Separation of the seed coat from the gum is still being studied, but is not expected to present major problems.

The yield of mill fractions from the milling process and their percent composition is shown in Table 2. The recovery and composition of the mill fractions will vary depending on the quality of the starting material, but these figures are considered representative. The exo-mesocarp (Fraction A) was the preponderant fraction from the pod and contains most of the pod sugar with lesser amounts of fiber and protein. This is the sweetest fraction but also contains most of the other taste components. It may have applications in fermentative ethanol production (Averginos et.al. 1980), as a source of sucrose, or as a flavor and sweetening ingredient in food products.

Table 2.--Yield and composition of Prosopis pod fractions after milling and separation

Fraction	Recovery in % of pod feed	Composition						
		% sucrose	% fiber	% dietary fiber[1]	% protein	% fat	% galactomannan	% ash
A=Exo-Mesocarp	58	31	18	35	11	2.5	--	4.4
B=Endocarp	26	5	36	61	6	5	--	3.8
C=Endosperm splits	6	--	10	--	8	--	60	--
D=Cotyledon	5	--	1	--	56	10	--	5
Sum of fractions	95	19	21	33	11.9	2.5	3.6	3.6
Pod unfractioned[2]	100	22	22	--	12	2.5	5	3.5

1) Method, Van Soest and Robertson, (1977).

2) The whole pod was milled and analyzed unfractioned.

Table 3.--Prosopis flours in cereal products

Product	Composition	Maximum percentage of added flour at which no significant change occurs.	Remarks about product with maximum percentage of added flour.	Remarks about product with more than maximal percentage of added flour.
Bread	Whole grain flour, water, salt, yeast + fraction A-flour.	8%	sweet, favorable color	unpleasant taste (hay) compact structure, reduced baking quality
Bread	Whole grain flour, water, salt, yeast, + Fraction B-flour.	15%	neutral	too rough reduced baking ability
Cookie	Whole grain mix using Fraction A	5%	neutral	unpleasant, bitter taste too brown (increased Maillard)
Cookie	Whole grain mix using Fraction B	20%	pleasant taste, improved structure	too rough

The fibrous exocarp, Fraction B, is very rich in fiber, but has lesser amounts of sugar and protein. Its best potential use appears to be as a fiber source in food products.

The seed coat-seed gum, Fraction C, is best used as a gum source while Fraction D from the seed cotyledons is the richest in protein. These figures are in general agreement with earlier compositional observations (Becker and Grosjean, 1980).

The results of incorporation of Prosopis flours into cereal products is shown in Table 3. Exocarp fraction A at 8% incorporation into the dough gives a bread with a sweeter taste and attractive color. Increasing this concentration causes taste and loaf structural problems.

Fraction B, containing the fibrous endocarp, is a better bread additive, probably because of its high fiber content. It did not greatly affect the taste, but excessive amounts made the bread very rough.

A similar pattern occurred when the pod fractions were incorporated into cookies; Fraction B was the best additive.

Samples were also baked containing 100% Prosopis flour instead of wheat (Data not shown). The fraction A flour does not build up any structure whereas the Fraction B flour achieves about 60% of the volume of a pure wheat flour bread. The taste of both examples is not satisfying but in connection with any commercial starch, and flavor improvements of the fractions it seems possible to use even higher amounts of Prosopis flour than described.

The starting pods used in these tests had a slightly bitter or astringent off flavor and aftertaste. These undesirable qualities often persisted into the baked product. Future experiments aimed at removing these off flavors are planned as is the search for a supply of better tasting pods.

Fraction C contains the galactomannan and the seed coat. The intention is to obtain a 100% gum fraction, but so far it was possible to achieve only 60% concentration in the semi-industrial scale.

Gum endosperm Composition: Gas chromatographic analysis showed that besides the galactose and the mannose, small amounts of other monosaccharides are present. The composition of galactomannan gum fraction without seedcoat is shown in Table 4.

Table 4.--Composition of the endosperm of fraction C as determined by Gas chromatography (aldonitrileacetate-method)

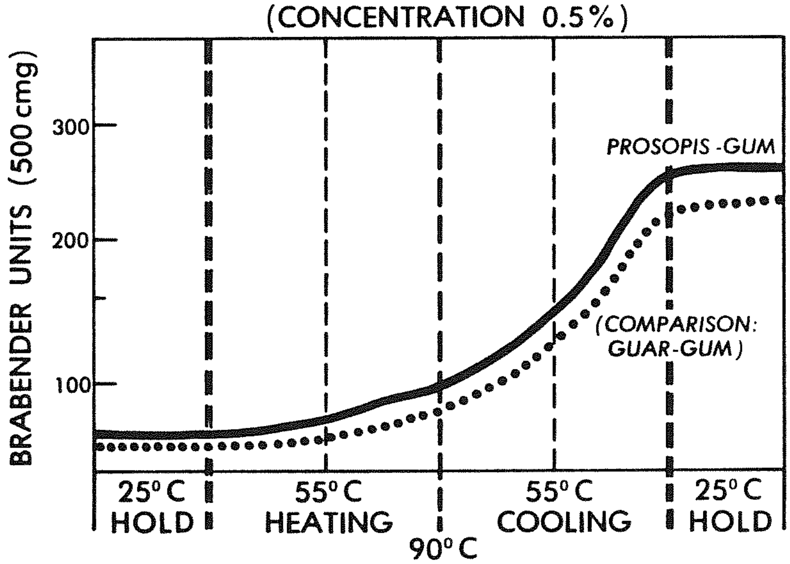
Monosaccharide	Retention time (min)	Concentration (%)
Rhamnose	99	0.225
Fucose	123	0.1
Arabinose	139	4.182
Xylose	156	1.957
Xylit	177	0.222
MANNOSE	221	56.47
Glucose	248	0.596
GALACTOSE	269	36.24
Total		99.99%

The galactose:mannose ratio is 1:1.6 which is very close to guar gum (1:2). It can be expected that other Prosopis species or even Prosopis velutina pods from different locations will show different ratios. Prosopis juliflora galactomman has been reported (Figueiredo 1976) to have a ratio of 1:4.2.

Gum viscosity: The amylogram in Table 5 shows that the Prosopis galactomannan is only partly cold water soluble. After the temperature was adjusted to 90°C and back to 25°C the viscosity was five times higher than without heating. This difference in hot and cold water solubility is rather amazing since, normally, the lower the galactose mannose ratio, the higher the cold water solubility. The final viscosity of the 0.5% solution is 250 BU and locust bean gum 160 BU (Meyer, 1981) at the same concentration after the same temperature treatment.

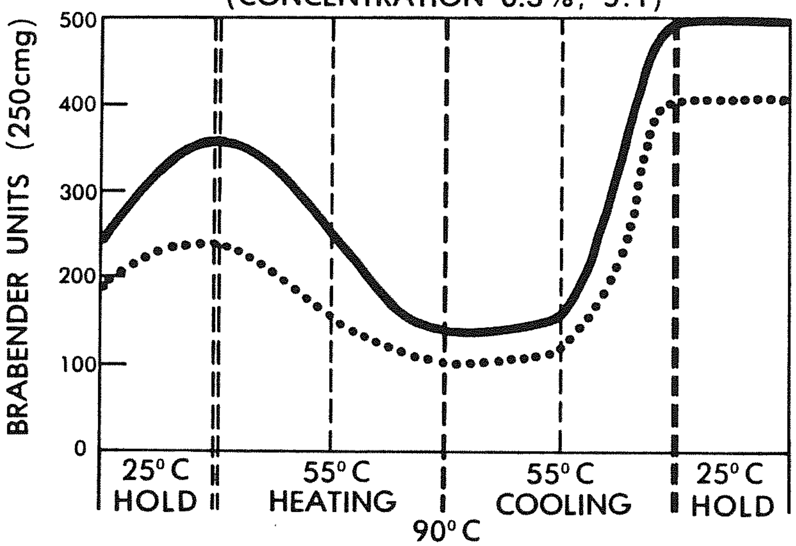
TABLE 5

VISCOSITY OF PROSOPIS-GALACTOMANNAN (CONCENTRATION 0.5%)



Interaction with Xanthan-gum: The experiment proved that Prosopis-galactomannan interacts with Xanthan gum. This is a very important ability of a galactomannan to be used in industry. The amylogram in Table 6 shows that a mixture of 0.25% Prosopis-galactomannan with 0.05% Xanthan has four times the viscosity of the pure galactomannan, even without heating the mixture. After heating a gel structure is developed which increases as the temperature goes down to 25°C. The final viscosity is 500 BU (250 cmg unit), which is about 5 times higher than the pure galactomannan. Further work will probably show even higher viscosity when the optimal combination with xanthan is found.

TABLE 6
VISCOSITY OF PROSOPIS-GALACTOMANNAN WITH XANTHAN-GUM (CONCENTRATION 0.3%; 5:1)



CONCLUSIONS

A milling and separation process has been developed to obtain four different fractions which are suited for use in food or as food products. The important steps in the process are product drying, the stone mill with special corrugated disc and product separation, involving three different types of classifiers. The procedure described is set up to process about 500 kg/hour.

Table 7 shows the fractions obtained through the described process and a summary of their compounds and possible applications. The lack of starch in the main fractions (A+B) seems to make it necessary to combine the Prosopis flour with a starch flour, such as wheat, potato or cassava. This would on one side reduce the necessary import of cereal flours for lesser developed countries and on the other side enrich the value of available but nutritionally poor raw materials such as cassava in these countries.

Some preliminary experiments in cereal products like bread and cookies containing Prosopis fractions have resulted in acceptable products. The range of application of the fractions in food products will be the subject of further studies.

The endosperm galactomannan gum deserves special attention since it has a similar galactose/mannose-ratio and viscosity as guar-gum. Interaction has occurred in experiments with xanthan-gum.

In spite of the promising outlook concerning application of Prosopis flours in or as food products, it shall not be forgotten that the use of a desert plant needs solution for technological as well as for climatic, geographic, social and economic problems.

TABLE 7.--FRACTIONS OF PROSOPIS PODS: MAIN COMPONENTS AND POSSIBLE APPLICATION

FRACTION A	FRACTION B	FRACTION C	FRACTION D
EXO-MESOCARP 55%	ENDOCARP 25%	ENDOSPERMSPLITS 10%	COTYLEDON 10%
	MAIN COMPONENTS		
SUCROSE 30-40% FIBER 15-20%	FIBER 35-45% PROTEIN 8-12%	GALACTO- MANNAN 50-70%	PROTEIN 60% FAT 8-12%
	POSSIBLE APPLICATION		
ETHANOL PRODUCTION SUCROSE EXTRACTION FOOD PRODUCTS	FOOD PRODUCTS	GUM	PROTEIN CONCENTRATE

LITERATURE CITED

Averginos, G. C. A. and Wang, D. I. C. 1980. Utilization of Mesquite and Honey Locust pods as feedstocks for energy production in Tree Crops for Energy Co-Production on Farms, YMCA of the Rockies.

Becker, R. and Grosjean, O.K. 1980. A compositional study of pods of two varieties of mesquite. J. Agric. Food. Chem. 28:22.

Felker, P., Clark, P. R., Osborn, D. F., Carnell, C. H. 1980. Utilization of Mesquite (Prosopis spp.) pods for ethanol production in Tree Crops for Energy Co-Production on Farms, YMCA of the Rockies.

Felger, R. S. and Moser, M. B. 1971. Seri Use of Mesquite. KIVA 37(1) 53.

Flynt, T. O. and Morton, H. L. 1969. A device for threshing Mesquite seeds. Weed Science 17(1):302.

Figueiredo, A. A. 1975. Lebensmittelchemisch relevante Inhaltstoffe der Schoten der Algarobeira. Dissertation, Wuerzburg (1975)

Meyer, D. 1981. Die Interaktion von Galatomannanen mit Xanthan. Diplomabeit, ETH Zuerich.

Van Soest, P. T. and Robertson, T. B. 1977. Analytical problems of fiber. In Carbohydrates and Health, AVI Publishing Co., Westport, Conn.

Stern, R. L., Karger, B. L., Keane, W. J. and Rose, H. C. 1969. Studies on the Gas-Liquid Chromatographic Separation of Diasterisomeric Esters. J. Chromatogr. 39:17.

THE NUTRITIVE VALUE OF PROSOPIS PODS

Robert Becker

Abstract.--The chemical composition, antinutrient content, and live animal feed value of the pod, seed, and mesocarp from several Prosopis species and sources were determined. Amino acid content and chemical score were compared with the FAO standard and observed PER and digestibility values. Effects of heating on PER and chick growth were attributed to compositional and antinutrient factors.

INTRODUCTION

Mesquite pods (Prosopis spp) have traditionally been used as a source of human and animal food in desert cultures. Desert Indians developed a variety of recipes using the whole pods, the pericarp, and seeds and recognized that certain trees produced better tasting pods.

In nature, the tree fills a valuable niche. Even the casual observer of a desert mesquite hummock quickly notes ample evidence of rodent habitation; the absence of low growing and fallen bean pods, bark stripped from the lower branches, numerous droppings, and usually a glimpse of a fleeing rabbit. In range situations, many trees are browsed free of beans as high as the livestock can reach. All of these observations point out the acceptability of the fruit as a palatable food, but say nothing about the nutritive value. We therefore initiated feeding studies designed to accurately evaluate the nutritive quality of Prosopis pods.

CHEMICAL COMPOSITION

The proximate composition was determined using AOAC (1975) procedures (Table 1). The whole pod protein content (N x 6.25) varies from 11 to 17%. This figure should be corrected for

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Table 1.--Proximate Compositon of *Prosopis* Fruit

Accession Number	Species	Part Analyzed	% H_2O	% Protein N x 6.25	% Fiber	% Ash	% Sugar
Trees Grown on Experimental Plots							
F0001	*P. glandulosa*	whole pod	2.2	14	20	3.4	34
F0020	*P. velutina*	whole pod	1.6	11	30	4.4	13
F0025	*P. velutina*	whole pod	2.1	14	19	3.1	28
F0032	*P. velutina*	whole pod	2.6	17	24	4.4	19
Mature wild or ornamental trees							
B0060	*P. velutina*	whole pod	4.3	12	31	4.1	19
B0201	*P. velutina*	whole pod	4.2	12	23	3.4	28
B0078	*P. velutina*	whole pod	2.2	12	23	4.8	22
B0078	*P. velutina*	pericarp	6.0	7	23	5.5	32
B0078	*P. velutina*	seeds	2.4	29	7	3.8	4
B0024	*P. glandulosa*	whole pod	7.5	11	22	3.3	26
B0024	*P. glandulosa*	pericarp	8.5	7	27	3.4	32
B0024	*P. glandulosa*	seeds	7.1	31	7	3.4	4
F0377	*P. glandulosa*	pericarp	8.1	8	30	--	13
F0372	*P. glandulosa*	pericarp	8.3	5	23	--	41
B0219	*P. pubescens*	whole pod	5.9	11	17	3.8	25
B0219	*P. pubescens*	seeds	7.4	26	--	--	--

Some of these accessions supplied countesy of P. Felker, Texas A and I University, Kingsville, TX and partially described in Felker (1980).

non-protein nitrogen (Becker & Grosjean, 1980), but serves as a useful comparison. The fiber reported is chemical fiber, that remaining after acid and alkali extraction. The ash content varies from 3.1-4.8% in the whole pod. The sugar varied from 13 to 34% of the whole pod and may be inversely related to fiber content.

Analysis of the pericarp and seed shows that the pericarp is rich in sugar and fiber. It has been shown that nearly all of the pericarp sugar occurs as sucrose (Becker & Grosjean, 1980). Little has been done to characterize the pericarp nitrogen. The seeds are readily processed into cotyledon and seed gum-seed coat fractions. The cotyledon is rich in protein and contains the typical legume seed sugars-sucrose, raffinose, and stachyose as well as phytic acid. The seed gum is a galacto-mannan with a viscosity comparable to carob and guar gum (Figueiredo, 1975). The seed gum adheres to the interior of the seed coat, both of which separate cleanly as one fraction from the cotyledon during milling.

The extreme range of pericarp composition is shown by the analysis of samples F0377 and F0372 where percent sugar varied from 13 to 41% (Table 1). The low sugar pericarp had an unpleasant taste often described as astringent and bitter with a lingering unpleasant aftertaste. The high sugar sample tasted sweet with little aftertaste. These taste components have not yet been identified but tannin is probably one major contributor.

The proximate composition of screwbeans (P. pubescens) is similar to the other Prosopis bean samples; rich in pericarp sugar and seed protein. The seed pericarp sugars have not yet been characterized.

Table 2.--Essential Amino Acid Content of Prosopis Seeds (mg/gm N)

	P. velutina	P. juliflora	P. pubescens
Isoleucine	173	220	191
Leucine	391	441	382
Lysine	237	250	332
Methionine + Cystine	67	71	73
Phenylalanine + Tyrosine	373	450	471
Threonine	144	130	173
Tryptophan	62	61	--
Valine	227	203	312

For amino acid analysis (Table 2) of P. velutina and P. pubescens, the seed cotyledon samples were separated from the seed coat and gum, hydrolyzed with hydrochloric acid in vacuo, and analyzed with a Durrum D500 automatic ion exchange analyzer. Triplicate samples were analyzed and the results, which agreed within 3%, averaged. Cystine and methionine were determined separately as cysteic acid and methionine sulfone after performic acid oxidation and acid hydrolysis. The analysis of P. juliflora is from Felker and Bandurski (1977). Comparison with the FAO Provisional Amino Acid Scoring Pattern (1973) as the reference protein indicated methionine + cystine are the first limiting amino acids for P. velutina, P. pubescens, and P. juliflora. This reference protein is for human nutrition; livestock, small animals, and poultry would have different nutritional requirements. On the basis of these scores, Prosopis protein has a nutritive value similar to other common legumes.

In a separate experiment, available lysine was determined in cooked and autoclaved P. velutina seed (AOAC, 1975). The seed contained 250 mg lysine/gm N of which 229 mg was available in the uncooked sample and 210 mg available in the autoclaved. Experimental error is such that there was no significant differences in availability.

An earlier investigation had demonstrated the absence of cyanide releasing compounds in P. velutina and P. glandulosa (Becker and Grosjean, 1980). Subsequent random samples from the California Sonora Desert, including those used in the feeding tests, also were found to be free of cyanogens. However, P. chilensis and P. tamarugo samples imported from Chile both released cyanide when macerated and mixed with acid. It is not likely that the cyanide in these samples is an artifact introduced as part of an insect fumigation treatment, but rather comes from the hydrolysis of a cyanoglycoside. This, plus an earlier observation by Hegnauer (1958) indicates all Prosopis samples should be considered cyanogenic until proven otherwise.

Preliminary tests in our laboratory have also demonstrated the presence of heat labile hemeagglutins and trypsin inhibitons. Seed extracts were seriologically mixed with trypsinated rabbit erythrocytes and moderate levels of agglutination observed (Kabat and Mayer, 1961). Trypsin inhibitor was spectrophotometrically determined using bovine trypsin andd TAME (Worthington, 1972). Heated extracts were free of both hemeagglutin and trypsin inhibitor activity.

Table 3.--Protein Efficiency Ratio (PER) and Digestibility of Pods and Seeds From Desert Plants.

Sample	Adjusted PER	% Digestibility Diet	Nitrogen
Prosopis velutina			
Pods, uncooked	0.71	66	56
Pods, Autoclaved			
5 min.	0.63	64	57
10 min.	0.61	65	55
20 min.	0.55	45	44
Seeds, uncooked	0.69	86	64
Autoclaved 10 min.	0.63	85	58
Pericarp, uncooked	0.32	63	49
Prosopis pubescens			
Screwbeans			
Pods, uncooked	-0.32	44	19
Pods, Autoclaved 10 min.	-1.35	40	4
Olneya tesota			
Desert Ironwood			
Seeds, uncooked	0.15	89	81
Seeds, Autoclaved 10 min.	0.46	85	74
Raw Soybean flour	0.54	66	--
Raw Soybean flour + Methionine	2.46	--	--

FEEDING EXPERIMENTS

The protein efficiency ratio (PER) was determined by a 28-day study using AOAC methods with diets containing 10% protein (Table 3). The samples were ground to 20 mesh, cooked for the indicated times at 120°C, and lyophilized. Pericarp and seed samples were mechanically separated and treated as above. *P. pubescens* and *Olneya tesota* are other desert legume trees which were included for comparison, as were the literature values for soybean flours. All diets are compared to an ANRC casein diet containing appropriately adjusted amounts of fiber and corrected to a PER of 2.50.

The uncooked mesquite pods had a PER of 0.71, which is somewhat higher than raw soybean flour. Autoclaving reduced the PER of the pods and the PER of flour prepared from mesquite seeds. This reduction in PER is probably due to the increased solubilization and accompanying increased water absorption and bulking effects of the seed gum when heated. Similar galacto-mannan gums are thought to interfer with nitrogen retention in poultry by reducing the food to feces transit time (Vohra *et al*, 1979).

These studies also show that mesquite pericarp is not a good source of protein. Its high fiber and low protein content make it a poor quality feed.

Prosopis pubescens pods have a negative PER which is made more negative by cooking. A negative PER means that the animal had a net loss in nitrogen, a very undesirable condition, and the material should not be used for animal feed. The negative PER is also probably due to the presence of a heat solubilized gum in the pods.

Table 4.--Body Weight of Chickens Fed Diets Containing *Prosopis velutina* whole Pods

Sample	Average Body Weight, gm	
Control	400	41
Prosopis velutina Pods		
Uncooked, 20% of Diet	360	25
Uncooked, 40% of Diet	260	20
Autoclaved, 20% of Diet	335	34
Autoclaved, 40% of Diet	348	71

The PER of _Olneya tesota_ is increased by cooking, the expected response. _Olneya_ has a poor amino acid profile and high levels of the antinutrient canavanine which probably are responsible for the low PER.

For the chick feeding experiments, other _P. velutina_ seeds were ground to 20 mesh, autoclaved as indicated and substituted into chick diets. Uncooked _P. velutina_ pod flour is an acceptable substitute for 20% of the corn in a corn-soybean fortified chick feed ration (Table 4). Substitution for 40% of the corn reduces average body weight, indicating an upper limit of substitution for good growth.

When autoclaved pod flour is substituted for corn in the diet, the chicks grew well at both the 20% and 40% level although the high standard deviation in the 40% diet makes this figure less reliable.

Table 5.--Metabolizable Energy Values for Chickens of _Prosopis velutina_ whole Pods and Several Common Feedstuffs

Feedstuff	Metabolizable Energy Kcal/gm
Prosopis velutina Pods	
Uncooked, 20% of Diet	1.65
Cooked, 20% of Diet	0.70
Corn	3.40
Oats	2.66
Alfalfa Meal	1.41
Wheat Bran	1.19

The metabolizable energy (ME) of a feed is the gross energy of the feed less the amount lost in the feces and urine (Table 5). When substituted for corn in the diet, uncooked _P. velutina_ pod flour ME is less than the traditional cereal grains such as corn and oats but more than high fiber commodities such as wheat bran. Cooked _Prosopis_ pod flour has a lower ME than uncooked, which when considered with the weight gain data demonstrate that there is no nutritional advantage to cooking the ground pods before feeding.

CONCLUSIONS

Consideration of the analytical data and the results of the feeding experiments indicate several factors are affecting the nutritive value of *Prosopis* pods. The protein of the raw pods is deficient in the sulfur amino acids. Low to moderate amounts of trypsin inhibitor and hemeagglutinin are present as antinutrients. Moist heating destroys the antinutrients and hydrates the seed gum. The cooked seed gum, even though subsequently dried, has an increased water binding capacity and bulking effect which significantly interferes with digestion in both rats and chicks.

The pod pericarp, by itself, has little available protein. Its main use would appear to be for its unique taste and as a high fiber source.

The seeds can be removed from the pod and substituted into animal diets. Separation of the seed into its major components should give a high protein cotyledon fraction with good feed potential, a gum fraction with exploitable characteristics, and the fibrous seed coat.

LITERATURE CITED

Association of Official Agricultural Chemists. 1975. Official Methods of Analysis, 12 ed.

Becker, R. and Grosjean, O. K. 1980. A compositional study of pods of two varieties of Mesquite (*Prosopis glandulasa*, *P. velutina*). J. Agric. Food Chem. 28, 22.

FAO. 1973. Energy and protein requirements. Food and Agriculture Organization, Rome, Nutrition Meeting Report Series No. 52.

Felker, P. and Bandurski, R. S. 1977. Protein and Amino Acid Composition of Tree Legume Seeds. J. Sci. Fd Agric. 28, 791.

Felker, Peter, Clark, Peter R., Osborn, Joseph F., and Cannell, G. H. 1980. Utilization of Mesquite (*Prosopis* spp.) Pods for Ethanol Production in "Tree Crops for Energy Co-Production on Farms" Solar Energy Research Institute, Estes Park, Colorado.

Figueiredo, A. A. 1975. Lebensmittelchemische relevante Inhaltstoffe der Schoten der Algarobeira (*Prosopis juliflora* DC). Ph.D. thesis, Wurzburg, Germany.

Hegnauer, R. 1958. Over De Verspreiding van Blauwzuur Bij Vaatplanten. Pharm. Weekbl. 93, 801.

Kabat, E. A., and Mayer, M. 1961. "Experimental Immunochemistry" C. C. Thomas, Springfield, Illinois.

Vohra, P., Shariff, G., and Kratzer, F. H. 1979. Growth Inhibitory Effect of Some Gums and Pectin for *Tribolium castaneum* Larvae, Chickens and Japanese Quail. Nut. Repts. Intnl. 19(4) 463.

Worthington Enzyme Manuel. 1972. Worthington Biochemical Corp. Freehold, New Jersey.

OVERVIEW OF MESQUITE UTILIZATION AT TEXAS A&I[1] UNIVERSITY

Peter Felker, Mark S. Lesney, Dom Smith, Isidro Reyes and Sharon Klass[2].

Introduction

From 1977 through 1980 work was conducted at the University of California, Riverside (UCR) to develop the energy producing, pod producing and nitrogen fixing characteristics of a genetically diverse collection of *Prosopis* (mesquite). From January 1981 till the present, the work has been conducted at Texas A&I University in Kingsville Texas. Since April 1978 the work has been supported by the U.S. Department of Energy.

Three field trials and several greenhouse experiments were conducted at UC-Riverside. A field study at UCR examined the biomass production of 32 *Prosopis* accessions that were irrigated when the soil water potential at the 30 cm depth was wet (0.6 Bar), medium (2.0 Bar), or dry (5.0 Bar) (Felker *et al*., 1981). At the end of three seasons growth, the trees were harvested, weighed, and representative whole trees chipped for moisture content determination. The fastest growing accession, *P. chilensis* (0009), had a dry matter productivity of 13.4 T ha^{-1} yr^{-1} when receiving an average annual rainfall plus irrigation input of 460 mm (18") (Felker *et al*., mss). Tremendous genetic diversity in thorn characters, prostrate versus erect growth habit, pod production and water use efficiency were observed in this trial. *P. chilensis* (0009) had approximately 30% thornless trees and tended to be erect. *P. chilensis* (0009) had a water use efficiency of 345 kg H_2O/kg dry matter and produced no pods in three seasons (Felker *et al*., mss). Many of the rangeland accessions from southern New Mexico, Arizona, and west Texas were prostrate and thorny with low biomass productivities. The water use efficiencies of these rangeland accessions were in the 2,300 to 2,600 kg H_2O/kg dry matter range and were closer to previously reported water use efficiencies of 1,671 and 4,800 kg h_2O/kg dry matter reported by McGinnies and Arnold, (1939), and Dwyer and DeGarmo (1970), respectively.

In contrast the southern Arizona *P. velutina* accessions tended to be the highest pod producers in early aged (1-5 year old) plantations. Twelve *Prosopis velutina* (0020) trees produced an average of 0.46 kg/tree on a

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1.22 x 1.22 m spacing for a pod production of 3,100 kg/ha (Felker *et al*., mss). This pod production occurred with only 370 mm of rainfall the previous winter and is an appreciable yield for the amount of water received.

A field trial at 1,500 m (5,000 ft) elevation in the mountains near Riverside compared the cold hardiness of 30 *Prosopis* accessions (Felker *et al*., in press). These accessions included California native mesquite, rangeland mesquite from Arizona, New Mexico and West Texas and fast growing selections from South America. The fast growing South American *Prosopis* possessed considerably less cold hardiness than North American mesquite. At the end of the first winter the biomass production of all these trees was estimated from basal diameter measurements using previously described regression equations (Felker *et al*., 1982). Most of the rangeland accessions were multistemmed and/or prostrate and possessed neither exceptional frost tolerance or high biomass production. California *Prosopis* accessions collected from trees grown at 900 m (3,000 ft) elevation at 35.7°N latitude had the greatest cold hardiness and a few large trees. The 14 most productive trees that survived the winter without damage were dug up and potted for use as breeding stock. One *P. chilensis* (0009), one *P. alba* (0039), and one *P. articulata* (0016) survived the winter and were successfully dug up and potted. The sole surviving *P. chilensis* (0009) tree had the greatest predicted biomass.

In 1979, a field trial was established in the California Imperial Valley to compare the biomass productivity of 55 accessions of arid adapted tree legumes. At the end of two seasons growth over a 100 fold difference in mean biomass production per accession was measured (Felker *et al*., mss). A few naturally occurring interspecific hybrids were observed with basal diameters ranging from 12 to 17 cm when measured two years from seeding in the greenhouse. A dozen of the most productive trees have been cloned by rooting of cutting techniques.

Greenhouse work at UCR confirmed that all 13 species in our collection (out of a total of 44 species in the genus) could nodulate and fix nitrogen (Felker and Clark, 1980). Some species were found that grew on a nitrogen free media at salinities equivalent to that of seawater (Felker *et al*., 1981). Greenhouse studies found that mesquite fixed nitrogen when its leaves were experiencing 47°C air temperatures and xylem water potentials of 3.3 MPa. Nodules were located 3 m from the soil surface in a phreatophytically simulated soil column in which the top 0.5 m of soil was drier than 2.2 MPa (Felker and Clark, 1982).

A South American ornamental *Prosopis* was identified and cloned that produced 73 kg of 44% sugar pods. These pods were easily fermented to alcohol by MIT fermentation researchers (Avgerinos and Wang, 1980).

The California work identified promising genetic material for many purposes, but unfortunately, the rainfall in the 8 million hectares of California desert ranges from 40 mm (1.6") to 200 mm (8") per year and is too low to support growth of anything without irrigation. California water supplies are presently overcommitted to be used for irrigation of new crops. In contrast Texas has 22 million hectares of mesquite already occurring under non-irrigated rainfall conditions. In January 1981, an opportunity arose to relocate the *Prosopis* energy research from UCR to the sub-tropical 28" annual rainfall region of South Texas at the Caesar Kleberg Wildlife Research Institute at Texas A&I University.

The California work was primarily screening work trying to identify superior physiologic properties and clones from among a large collection of *Prosopis*. In contrast the Texas A&I work has shifted to development of efficient cultural practices that would be amenable to scale up of large scale commercial production.

The rationale for developing mesquite plantation practices for Texas when there is already so much mesquite present, is that we wish to develop high production technologies (14-16 T ha^{-1} yr^{-1}) that are both renewable and environmentally sound. Harvesting dense stands of existing brush may yield large quantities of fuel the first harvest, but the ensuing unmanaged regrowth production may be considerably less than required to support moderate sized chemical or electrical generating industries. Furthermore in some areas, the *Prosopis* wood resource is too disperse to allow economical harvest and transportation.

Texas A&I plantation establishment and field work

The seedlings are being grown in specially fabricated plant bands that are 3.8 x 3.8 x 38 cm to allow development of a long tap root. A greenhouse experiment was conducted to develop a light weight soil mix that would be low in nitrogen and high in phosphate to stimulate nitrogen fixation. Accordingly a greenhouse factorial experiment with 3 levels of lime, phosphate, and micronutrients was conducted with a peat, perlite, vermiculite soil mix for use with *Prosopis*. Our seedlings are inoculated with a rhizobia strain to provide good nodulation in the seedling stage. A tractor pulled tree planter was modified with the assistance of Dr. Willie Ulich of Texas Tech. University. This device can easily plant 300 seedlings in 15" deep containers per hour while simultaneously side dressing with phosphate. A preplant herbicide trial with Surflan, Goal, Devrinol, Dual, and Lasso at 2 rates and 3 replications is underway. The insecticides pydrin, sevin XLR, and toxaphene are being compared for control of twig girdlers and orthene is being used for control of psyllids.

Pod production by *Prosopis* is being examined in two field experiments. The first experiment is designed to compare pod production from four promising pod producers of a diverse genetic background. The experiment consists of 4 replicates in a Latin square design. Each replicate consists of 25 trees in a 5 x 5 array on a 6 x 4 m spacing. The accessions being examined are: the best pod producing accession from the California Imperial Valley field trial, *P. pubescens* (0627) which is a screwbean; the best pod producing accession *P. velutina* (0509) from the

UCR dry irrigation treatment plots; a 41% sugar pod producing California native P. *glandulosa* var *torreyana* (0372); and an erect early pod producing *P. alba* (0900) from the UCR dry irrigation treatment that had small thorns and sweet pods. A second field experiment has been established to examine the effect of soil phosphate applications on pod production. This is important since phosphate is important for grain/fruit production and since phosphate is required for nitrogen fixation. An early pod producing California *P. velutina* accession (0586) with high protein (17%), low sugar content (19%) pods, and an erect tree shape was chosen for this experiment. Three soil treatments of 0, 60, and 120 kg P_2O_5 per hectare have been made using three replicates in a Latin square design. Again each replicate consists of 25 trees in a 5 x 5 array on a 6 x 4 m spacing.

Pod production is being examined in the progeny of a thorny *P. alba* (0388) tree which produced 73 kg of 25 cm long, 44% sugar pods. These pods were easily fermented to ethanol by Avgerinos and Wang (1980) of MIT. One hundred and thirty of these trees have been planted as a solid block with a 7 x 7 m spacing to examine pod production and possible segregation of thorn and pod production characteristics.

In addition to answering scientific questions on pod production, a seed orchard has been planted to provide seed for requests from less developed countries (LDC's). We receive numerous requests for seed from LDC's which we are unable to fill because of lack of seed quantities. One hundred trees of 8 accessions have been planted on a 7.5 x 7.5 m spacing to provide high quality seeds.

The accessions used in the seed orchards are as follows:

Accession Used	Parent Accession	Species	Reason for Interest
0166	0166	*P. alba*	Best woody biomass producer
0009	0009	*P. chilensis*	Second best woody biomass producer
0618	0285	*P. alba*	Good biomass producer
0591	0039	*P. alba*	Good biomass producer
0846	0001	*P. glandulosa* var *torreyana*	Highest California native pod producer
0509	0020	*P. velutina*	Highest Arizona native pod producer

0593	0016	P. articulata	High salt tolerance, high biomass producer but large thorns and low frost tolerance
0388	0388	P. alba x P. velutina hybrid	High sugar content pods

Ornamental uses of Prosopis are being examined on a 0.8 ha plot. In this plot, fast-growing thornless evergreen south American accessions are being examined at wide (9 m) spacings to allow the trees to achieve a broad shady canopy.

A screening nursery has been established to allow observation for new plant characters from unusual sources. P. alba selections collected at 2400 m elevation in the Chilean Atacama desert look quite promising as frost tolerant thornless evergreen ornamentals. In contrast over 100 Prosopis trees from parents in Peru with large thick sweet pods all succumbed in last years cold weather.

Two field plots have been established to study woody biomass production. The first plot established in April 1981 consisted of sixteen blocks (0.07 ha each) of 144 trees each on a 2.5 x 2.5 m spacing. The plan was to harvest 4 blocks every year for four years. Unfortunately our first year planting was plagued by flooding from unseasonal high rains, intense competition from johnsongrass and sunflowers, rabbit browse, and mismanagement of herbicides which killed many of the trees. Since biomass production estimates from these plots would be unreliable, they are being used for replicate weed and insect control measures.

In April 1982, our first plot of a clonally propagated thornless high biomass Prosopis producing clone B_2V_{50} was established. Three replicates of 12 trees each (which are bordered by two rows of a closely related accession selection) will be harvested each year for 3 years.

Clonal Propagation by rooting of cuttings and tissue culture

Mesquites self-incompatible, obligately outcrossed flowers maintain a very high degree of genetic diversity within Prosopis. Seeds from the same tree are half-siblings and show enormous variation in morphological, ecological, and physiological properties. Seedlings originating from the same female tree may have 4 to 5 fold difference in growth rate, they may or may not have thorns, they may have low or high pod production and they may exhibit variation in bud burst, leaf morphology, and frost tolerance. This extreme variation has made it necessary to develop asexual propagation methods. Young actively growing greenhouse stock have been shown to be moderately easy to root in the spring of this year, but quite difficult to root in the fall and winter.

Cuttings taken from out-of-doors grown mature trees generally have low (1% or less) rooting percentages. The effect of environmental parameters on the rooting of cuttings is being examined in growth chamber studies because of the strong environmental component in rooting of cuttings. Photoperiods of 8, 12, 16 and 24 hrs did not markedly effect rooting of cuttings. In contrast air temperature strongly influenced the rooting of cuttings with an optimum air temperature for both stock plants and rooted cuttings of 35°C. The work on the effect of environmental parameters on rooting of cuttings will be a major focus of our research.

To compliment the research on asexual propagation by rooting of cuttings, work on *in vitro* propagation of *Prosopis* by tissue culture has been initiated. Techniques have been developed that routinely surface sterilize 90% of the explants. It has been routinely possible to obtain lateral bud break and shoot development from excised stem segments. A low percentage of the resultant shoots have rooted in agar. Unfortunately the resultant plantlets have generally yellowed and then senesced.

Economic - Social analyses of Biomass Energy Farming

Our costs analyses indicate that mesquite chips can be produced in a renewable fashion for $28.00 per dry metric ton or $1.50 per million Btus. These costs include a $25/hectare/yr return to the land owner and a $15.70 harvesting and chipping cost per dry metric ton using Dr. Ulichs harvester. A major limitation to the use of wood for industrial fuel has not been the cost, - but rather the unavailability of sufficient quantities to supply commercial scale electrical generating or petrochemical industries. A 15.7 dry ton/hectare/yr (7.0 dry ton/acre/year) productivity would allow operation of a 300 ton per hour petrochemical plant or a 500 megawatt power plant on a 15 mile radius if all the land within that area were farmed. The area enclosed by that circle would be 150,000 ha (380,000 acres). The wood fuel sales from that area would be 67 million dollars per year. In contrast to oil and gas sources of energy, most of the costs of the wood fuel would be paid to tractor drivers, machinery dealers, and the agrichemical industry. It can be seen that biomass farming of such large acreages would create entirely new renewable industries and employment. The conversion of the woodfuel to either electricity or chemicals would create additional jobs and revenue.

Conclusions

Pilot scale techniques for commercial scale production of advanced *Prosopis* lines previously identified at the University of California, Riverside is underway at Texas A&I University. Considerable progress is being made but it will be at least several years before the requisite techniques are developed. Lack of techniques to produce commercial quantities of asexually reproduced high biomass producing seedlings is probably the most significant technical barrier to commercialization.

Research level techniques are now available at Texas A&I to produce high production of renewable *Prosopis* feedstock. Harvesting and wood energy conversion techniques are available at Texas Tech and elsewhere. We hope that an integrated production, harvesting, and energy conversion pilotscale demonstration facility can soon be established.

LITERATURE CITED

Avegerinos, G.C., and D.I.C. Wang (1980). Utilization of mesquite and honey locust pods as feedstocks for energy production in "Tree Crops for Energy Co-production on Farms" Solar Energy Research Institute/DOE. National Technical Information Services. Springfield, VA 22161.

Dwyer, D.D., and H.C. DeGarmo (1970). Greenhouse productivity and water use efficiency of selected desert shrubs and grasses under four soil moisture levels. New Mexico State Univ. Agric. Exp. Sta. Bell. 570:1-15.

Felker, P., and P.R. Clark (1980). Nitrogen fixation (acetylene reduction) and cross inoculation in 12 *Prosopis* (mesquite) species. Plant and Soil 57:177-186.

Felker, P., G.H. Cannell, and P.R. Clark (1981). Variation in growth among 13 (*Prosopis*) mesquite species. Experimental Agriculture 17:209-218.

Felker, P., P.R. Clark, A.E. Laag, and P.F. Pratt (1981). Salinity tolerance of the tree legumes mesquite (*Prosopis glandulosa* var *torreyana*, *P. velutina*, and *P. articulata*), algarrobo (*P. chilensis*), Kiawe (*P. pallida*) and tamarugo (*P. tamarugo*) grown in sand culture on nitrogen free media. Plant and soil, 61:311-317.

Felker, P., P.R. Clark, J.F. Osborn, and G.H. Cannell (1982). Biomass estimation in a young stand of mesquite (*Prosopis* spp.), Ironwood (*Olneya tesota*), Palo verde (*Cercidium floridium* and *Parkinsonia aculeata*) and Leucaena (*Leucaena leucocephala*). J. Range. Manage. 35:87-89.

Felker, P., and P.R. Clark (1982). Position of mesquite (*Prosopis* ssp.) nodulation and nitrogen fixation (acetylene reduction) in 3-m long phraetophytically simulated soil columns. Plant and Soil 64:297-305.

Felker, P., P.R. Clark, P. Nash, J.F. Osborn, and G.H. Cannell (1982). Screening *Prosopis* (mesquite) for cold tolerance. Forest Science. In Press.

McGinnies, W.G. and J.F. Arnold (1939). Relative water requirement of Arizona range plants. Tech Bulletin 80, University of Arizona Agric. Exp. Station. 167-245.

MESQUITE UTILIZATION: FROM THE STUMP TO FINISHED PRODUCT[1]

Robert E. Larson, and Mohammed E. Sodjoudee[2]

Abstract.--Three dry kiln schedules (mild, intermediate, and severe) were tested for mesquite (Prosopis juliflora (SW.) DC) 4/4 lumber. Results indicated mesquite could be favorably dried in as few as nine days with some degrade, or up to fifteen days with negligible degrade.

Following drying, the lumber was distributed to four wood manufacturing firms for rating the wood characteristics and trial demonstrations. The woodworkers were favorably impressed with the final products and indicated a strong interest in the use of mesquite in the future.

INTRODUCTION

Mesquite trees are found in approximately 70 million acres in the southwestern United States on the sandy soil of plains and mesas of arid and semi-arid climates below 5500 feet in altitude (Little 1950) and (Record 1943).

The trees generally exist in two forms: either a single stem or a bush-like stem. The bush-like form is used mostly for fuelwood or fenceposts (Wiley 1977). The tree normally attains a height of about 15 to 20 feet and a diameter of up to 18 inches. Due to adverse site conditions an average mesquite tree will grow at a radial rate of about 0.015 inch per year and reach a 9 inch diameter in 60 years (Benson and Darrow 1944). The term mesquite in the United States refers to varieties of Prosopis juliflora, which are commonly named as honey mesquite, velvet mesquite and screw-bean, Prosopis pubescens (Lamb 1975). Mesquite wood is hard, heavy, strong and close-grained. The heartwood is grayish-brown (western honey mesquite) and the sapwood band is thin and yellow. It has a course texture with an irregular grain pattern which makes the wood quite unique and aesthetically pleasing.

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[1]Paper presented at the Mesquite Utilization Symposium. Texas Tech University, Lubbock, Texas, October 29-30, 1982.

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Mohammed E. Sodjoudee, Graduate Student, N.A.U. School of Forestry

Because of the tree's extensive root system, it absorbs much of the available moisture from the soil and consequently, indirectly inhibits the growth of desirable grassland species. Thus, it has created a problem in range management and the tree is considered a weed species.

There is a strong demand in the Southwest for mesquite to be used as fuelwood due to its relatively high specific gravity of 0.68 (green volume, ovendry weight). The heat of combustion for mesquite heartwood is 8600 Btu per ovendry pound (Wiley and Manwiller 1976). However, because of mesquite's aesthetically pleasing appearance and availability, there has been increased interest in the use of this species for manufactured products.

PROBLEM

The purpose of this study was: (1) to develop satisfactory dry kiln schedules which could be used commercially to dry mesquite with a minimum amount of degrade and, (2) to demonstrate the potential of mesquite for lumber in the manufacture of furniture and specialty products.

METHODS AND MATERIALS

Green mesquite (moisture content approximately 55 percent), 4/4, random width (6" to 10") 8 feet long lumber was obtained from a private firm in Tucson, Arizona. All lumber was end-coated with a silicone sealant, after being received at the N.A.U. School of Forestry and stored in a conditioning room at a temperature of 70 F. and a relative humidity of approximately 95 percent.

Each board was planed to a thickness of 1.00 inch and numbered prior to being stickered for drying. Three dry kiln schedules were selected for drying using approximately 80 board feet per charge, and one replication per schedule.

Based on the similarity of green moisture content and specific gravity (S.G.) of mesquite to white oak, schedule (T4-D2) was used from the Dry Kiln Operator's Manual (U.S. Print. Off. 1961). This first (mild) schedule was followed by an intermediate schedule, T8-D4. The final schedule, T12-D6 was the most severe schedule used in drying the mesquite.

Apitong stickers with dimensions 3/4"x 2" x 26" were used and spaced at 23-inch centers over bunk supports.

Restraint or top-loading of charges was accomplished by placing concrete blocks on top of the lumber. Top-load weight approximated 112 pounds per square foot.

The dry kiln used for this study, was a Despatch Model 95257L electric testing oven. Air circulation speed was 600 lineal feet per minute for each charge.

Six sample boards were selected to monitor the drying rate of each charge. The target moisture content (m.c.) was 8 percent for this study since the lumber was to be used in the manufacture of furniture and other items.

Figure 1. illustrates a typical charge of mesquite boards that were dried.

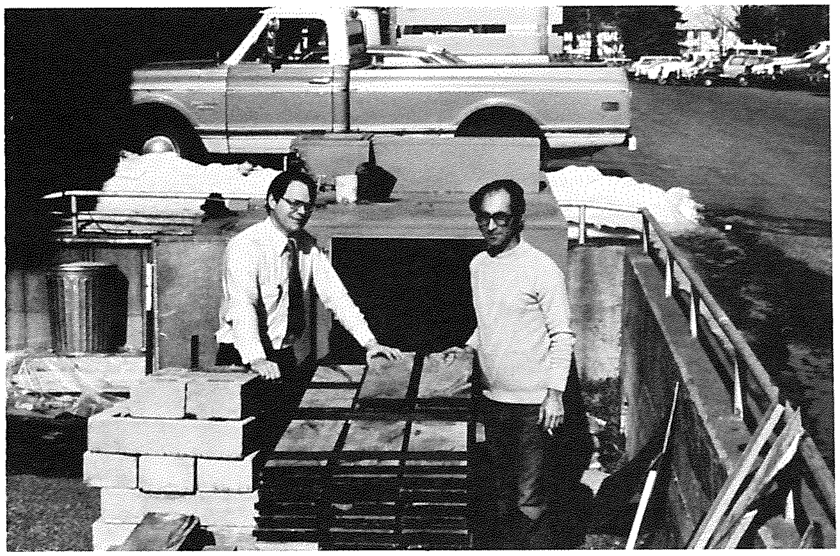

Figure 1.--Authors preparing a charge of mesquite for kiln drying.

Case hardening tests and m.c. tests were completed for samples from each charge. A conditioning period of 22 hours was employed to relieve stresses in the wood.

Following drying, each board was inspected for warp, checking surface ripples, evidence of collapse and honeycombing. In addition, bow, twist, and crook were measured to the nearest one-eighth of an inch from the flat surface.

The kiln-dried lumber was delivered to the following firms:

- Wood Kraze, Flagstaff, Arizona
- Wood Haven, Flagstaff, Arizona
- Michaelson's Fine Woodworkers, Phoenix, Arizona
- Pauling Cabinets, Phoenix, Arizona

Prior to this study none of the firms had ever worked with the mesquite species. The manufacturers were encouraged to make whatever they wished. In addition, they agreed to evaluate the characteristics and workability of the wood, and provide photographs after the completion of the projects.

RESULTS AND DISCUSSION

Kiln Drying of 4/4 Mesquite

A summary of the moisture content values and specific gravity for each charge (table 1.) indicates and average S.G. of 0.68 and an average green moisture content of 55 percent for the sample boards in the charges.

Table. 1. Average values for specific gravity and initial green moisture content of mesquite samples

Charges	Values						
	I	II	III	IV	V	VI	Average
Specific Gravity*	.67	.64	.61	.64	.77	.73	.68
Initial MC %	46.43	65.00	53.00	52.00	53.00	61.00	55.00
Final MC %	8.28	9.75	8.84	5.67	8.83	7.67	8.17

*Green volume, oven-dry weight basis.

The predominant defect associated with drying of mesquite was warp (table 2.) and the frequency which it occurred increased with the severity of schedule.

Table 2. Drying defects found in individual mesquite boards

Treatment	Charge	Warp	Checking	Collapse	Honeycomb	Total Number of Boards
Mild T4D2 (350 hours)	1 2	6 10	1 0	0 0	0 0	45 34
Intermediate T8-D4 (300 hours)	3 4	14 17	1 2	0 0	0 0	35 45
Severe T12-D6 (225 hours)	5 6	27 35	5 8	0 0	0 0	40 46

In the chi-square test (table 3.) there was a significant difference at the 0.05 level between treatments.

Table 3. Chi-square test comparing warp for different kiln schedules

Treatment	Calculated X^2	Table $X^2(.95)2df$
Mild versus Intermediate	6.53	5.99
Mild versus Severe	44.39	5.99
Intermediate versus Severe	18.70	5.99

There was no collapse or honeycombing evident in any of the boards dried. This observation coincides with other data collected (Wiley 1977) where the author suggested the reason as being the high dimensional stability of mesquite.

End-checking was found to be minimal in the boards but increased in frequency with the severe schedule (table 2.). The main reason could be attributed to the silicone sealant end-treatment placed on all the boards prior to drying.

Relationships between moisture content, drying times, and wet and dry bulb temperatures are illustrated for the mild, intermediate, and severe schedules in figures 2-4.

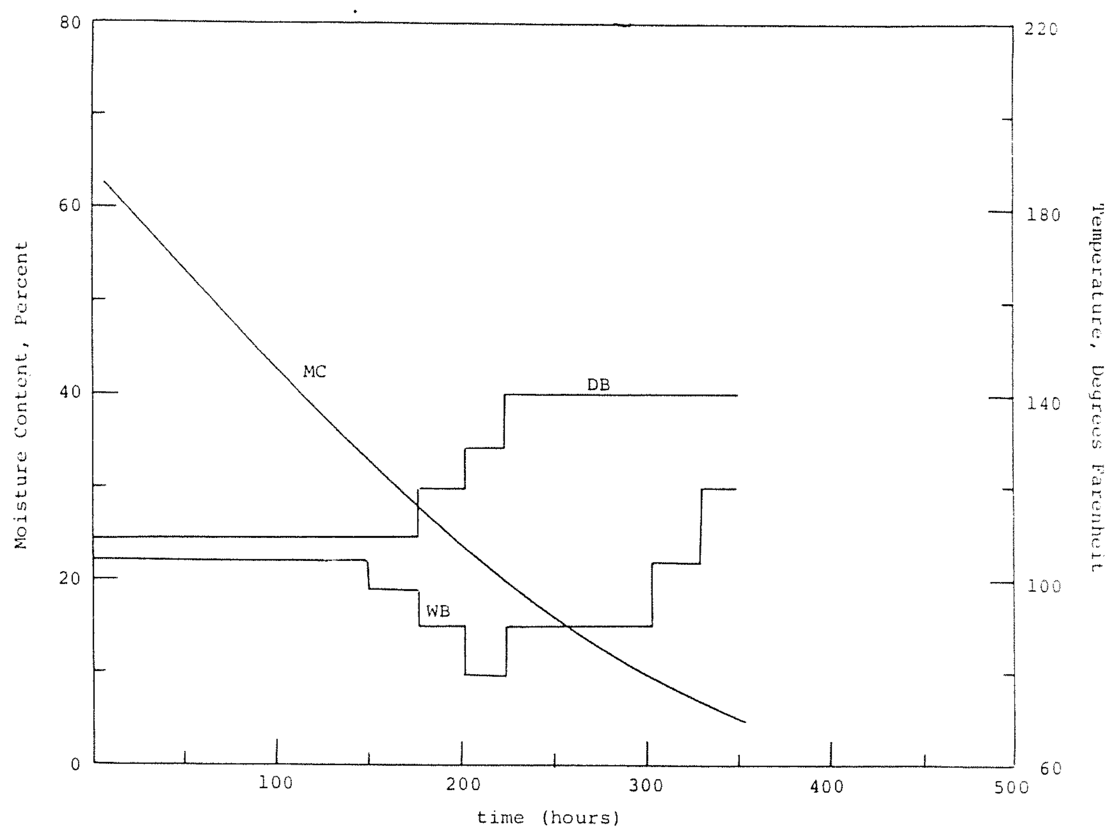

Figure 2. Mild kiln schedule: dry bulb and wet bulb temperatures and moisture content over time

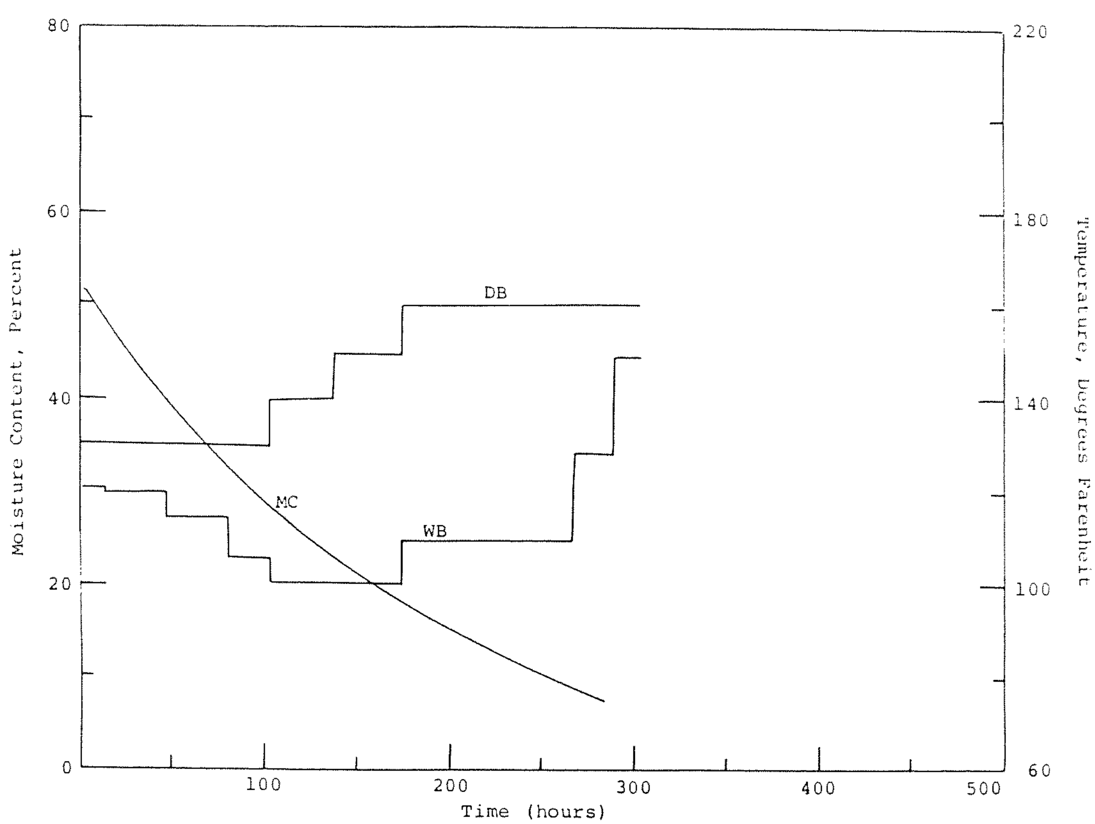

Figure 3. Intermediate kiln schedule: dry bulb and wet bulb temperatures and moisture content over time

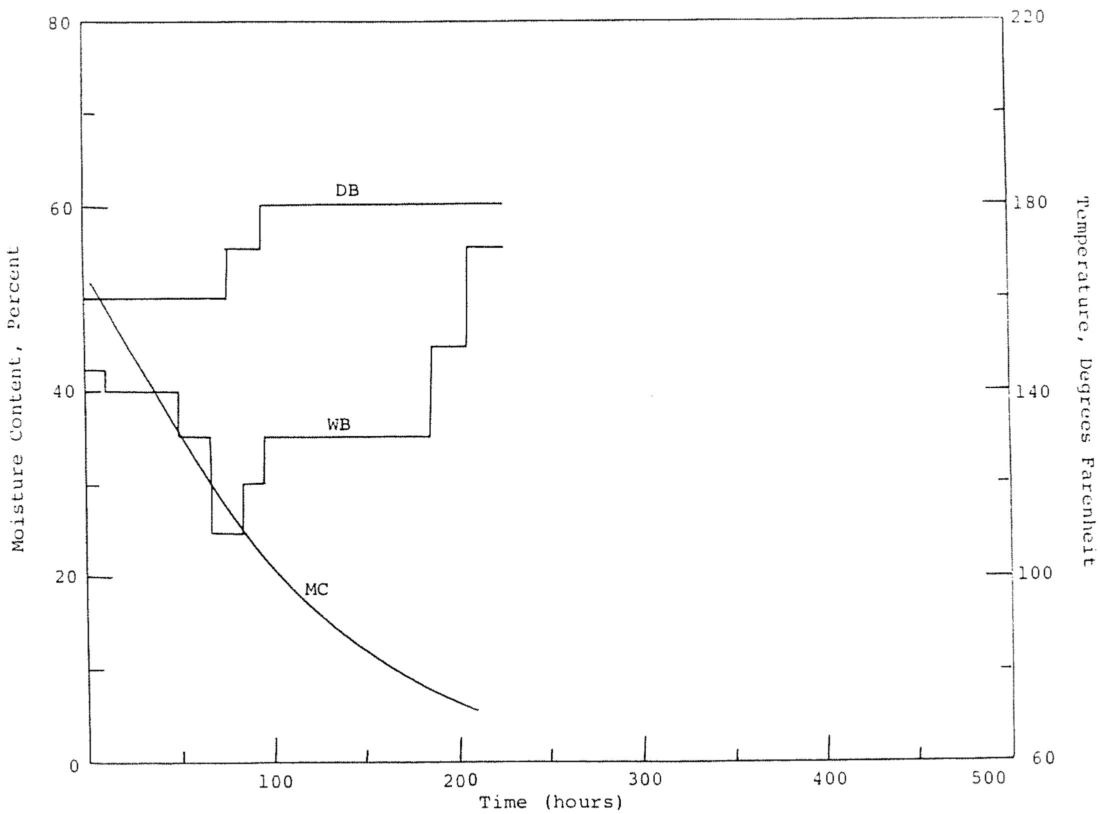

Figure 4. Severe kiln schedule: dry bulb and wet bulb temperatures and moisture content over time

Mesquite lumber can be kiln-dried quickly to an 8 percent M.C. employing a severe schedule of 225 hours (9.38 days) with degrade problems of warp. If top-loading of a charge were not used, an even greater amount of warp would be expected to be observed.

Drying time of mesquite employing the mild schedule was 350 hours (14.58 days). Although the drying time of the wood in the kiln increased by 56 percent as compared with the severe schedule, the trade-off in the form of less degrade and hence, higher quality lumber may favor this schedule for commercial applications.

Trial Demonstrations of Mesquite Wood

Unique and varied products were made from the wood distributed to the custom wood manufacturers. They ranged in size from a large solid mesquite desk (figure 5.) and cabinet (figure 6.) to smaller items illustrated in figures 7 and 8.

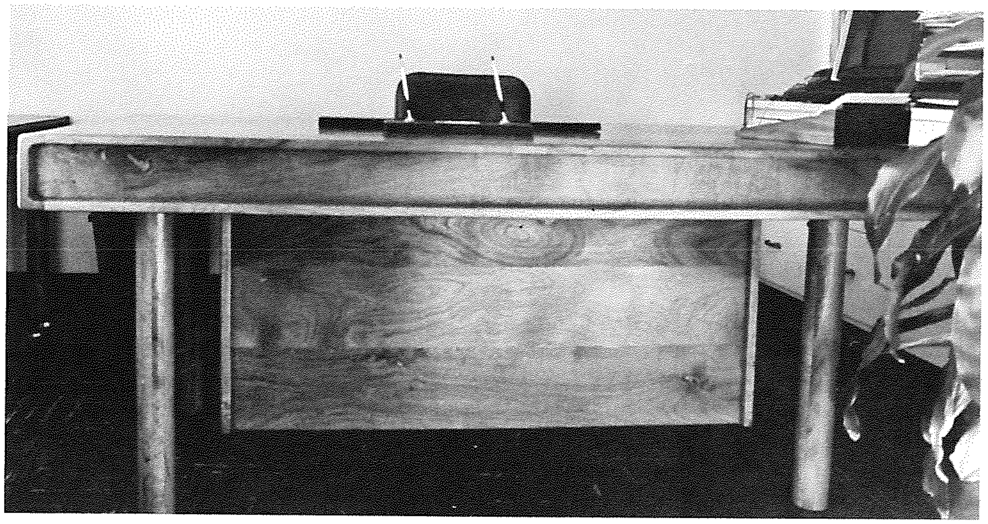

Figure 5.--Mesquite desk of 4/4 lumber and laminated legs.

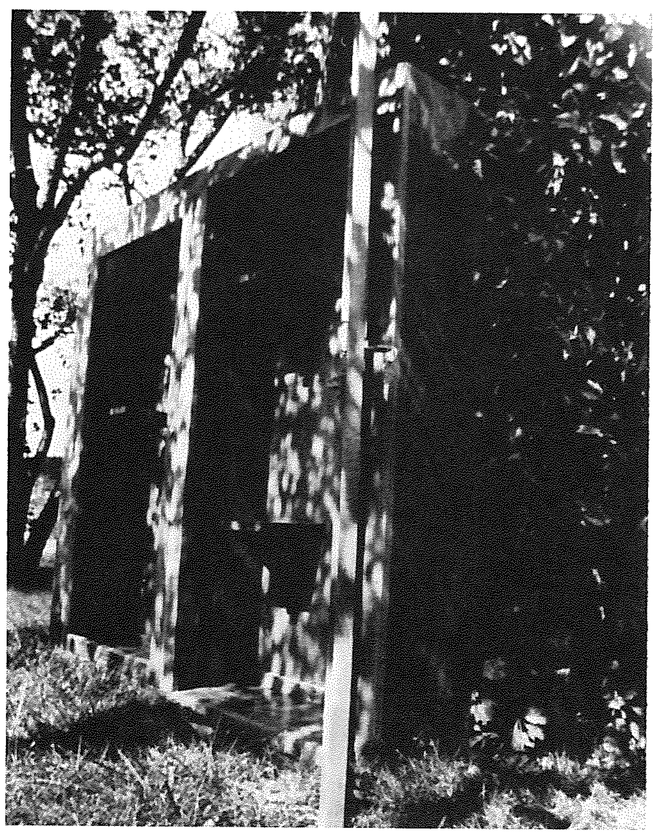

Figure 6.--Display cabinet of 4/4 mesquite encased with glass.

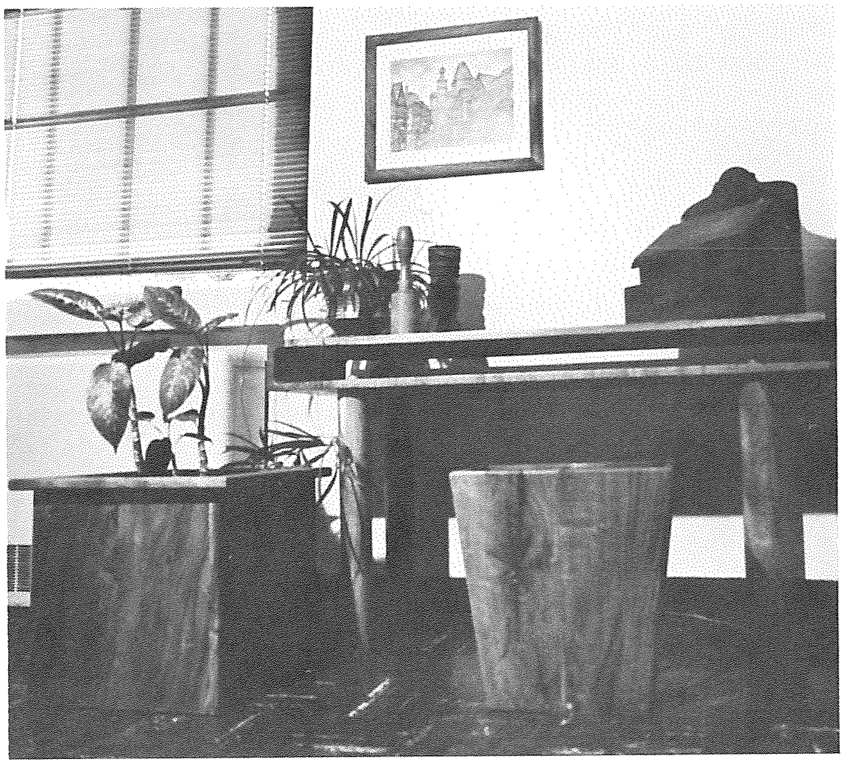

Figure 7.--Assorted products made from 4/4 mesquite: planter, maul, candlestick holder, picture frame, colonial box, and wastebasket.

Figure 8.--Game table of 4/4 mesquite with purpleheart wood inlay.

After the products were manufactured, each of the four custom woodworkers responded to a questionnaire regarding mesquite. Ratings for mesquite were based upon the woodworkers' experience with other hardwood species (table 4.).

Table 4. Wood manufacturers' ratings of mesquite lumber

	Above Average	Average	Below Average	Poor
Sanding	X	XX	X	
Machinability	XX	XX		
Natural defects	X			XXX
Drying defects		XXXX		
Gluing		XXXX		
Finishing	X	XXX		
Handworking characteristics	XX	XX		
Aesthetic beauty	XXXX			

The highest rating given to mesquite by all firms was the aesthetic beauty of the wood. Distinct grain patterns resulting from the normal cross grain found this species makes the appearance quite bold and rugged. Above-average to average ratings were given for the following characteristics: Machinability, defects due to drying, gluing, finishing and handworking. Sanding of this dense wood produced varied responses ranging from above average to below average. The major limiting factor of using mesquite was identified by three firms as being natural defects of the wood. These defects were a problem to those firms manufacturing the larger pieces of furniture since a greater proportion of the wood had to be discarded as compared with manufacture of smaller projects.

From a marketing perspective, all firms believed mesquite had definite potential, especially for use in small furniture pieces, turnings, and novelty items. When asked if mesquite were to be made available in the immediate future, all firms responded that they were moderately to greatly impressed, and that they would be interested in acquiring more of it for their operations.

SUMMARY AND CONCLUSIONS

This study was designed to investigate the potential of mesquite wood for manufacture as opposed to its present dominant use for fuelwood. Three kiln schedules were developed to dry the wood from the green condition to a moisture content of 8 percent. Kiln-drying time for this species ranged from 225 hours to 350 hours. As drying time was reduced by employing a more severe schedule, there was an increase in the number of defects found in a charge. End-coating boards with a silicone sealant seemed to be an effective method to reduce checking.

Wood firms responded favorably to the overall woodworking characteristics of mesquite lumber. Even though natural defects were cited as being limiting to larger projects, all of the custom woodworkers indicated they would use more mesquite in the future, if it were available. Since much of the mesquite resource in the southwest consists of smaller diameter trees, a strong possibility for the increased utilization presently exists in the form of manufacturing lumber for use in furniture and specialty items.

LITERATURE CITED

Benson, L. and R.A. Darrow. 1944. A Manual of Southwestern Desert Trees and Shrubs. University of Arizona, Tucson, AZ. 411 p.

Lamb, S.H. 1975. Woody Plants of the Southwest. The Sunstone Press, Santa Fe. N.M. 177 p.

Little, E.L. Jr. 1950. Southern Trees: A Guide to the Native Species of New Mexico and Arizona. Agr. Handbk. No. 9. U.S.D.A. Forest Service. U.S. Govt. Print. Off. pp. 65-67.

Rasmussen, E.F. 1961. Dry Kiln Operator's Manual. Agr. Handbk. No. 188. U.S.D.A. Forest Service. U.S. Govt. Print. Off. 197 p.

Record, S.J. and R.W. Hess. 1943. Timbers of the New World. New Haven: Yale University Press, New Haven, Conn. 640 p.

Wiley, A.T. and F.G. Manwiller. 1976. Market Potential of Mesquite as Fuel. Forest Products Journal 26(9):48-51.

Wiley, A.T. 1977. Mesquite--A Possible Source of Energy. Forest Products Journal 27(7):48-51.

Wiley, A.T. 1977. Moisture Relations of Mesquite Wood. Texas Forest Products Laboratory Publication 113, Texas Forest Service, Lufkin, TX.

ORNAMENTAL LANDSCAPING AS A MARKET FOR MESQUITE TREES[1]

Nancy A. Allworth-Ewalt[2]

The decrease in availability of irrigation water in the plains area is causing many people to search for native landscape plant materials which require little or no water. Mesquite species could be promoted and marketed as ornamentals to the economic advantage of both rangeland owners and home owners who use them.

INTRODUCTION

Large areas of arid and semi-arid lands exist in nearly all parts of the world. The people who make their homes in these dryland areas, especially in some regions of the United States, have tended to try to surround themselves with landscapes which are typical of much wetter and more temperate zones. As warnings are sounded about the depletion and eventual loss of water resources, more people are looking for ways to prepare themselves and their surroundings for the predicted lack of irrigation water. In this search, many are turning for landscaping purposes to native species of plants which can survive with little or no water other than natural rainfall. Inevitably, one of the genera which are attracting attention is mesquite.

Of the forty or so known species of mesquite (*Prosopis*), several are currently being planted as ornamental landscape plants. *Prosopis alba*, *P. velutina*, *P. glandulosa*, and *P. chilensis* are among species being used. In addition to these, at least one hybrid has found its way into landscape use.

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HISTORICAL USEFULNESS OF MESQUITE

Historically, the mesquite tree's usefulness for food, medicine, and other purposes made it a valuable and sought after tree. It has only been over the last seventy years that the general attitude toward mesquite has changed from one of respect and appreciation to a negative view of these species as some of the worst rangeland pests in existence.

Southwestern Indian tribes made multiple uses of the species found in their areas. Mesquite could be depended upon to produce good crops on a regular basis, and best of all, produced its best and largest crops in the most severe dry spring and summer seasons. *Prosopis glandulosa* has been known to bloom and produce fruit up to four times a year (Simpson 1977). In California, after the Spanish conquest, mesquite trees with sweet tasting pods were brought into the area and planted at some of the missions (Leon-Portilla 1973).

Mesquite beans were used at nearly any stage of ripeness. Various refreshing drinks were prepared from the pods and some of these were allowed to ferment into a mild beer-like drink. Mesquite flowers were also eaten; the inner bark was used as a substitute for rennet, and parts were used to make candy. Mesquite was widely used medicinally, most commonly for eye ailments, but also for sore throats, topical pain relief, intestinal disturbances, as a disinfectant, and for many other problems.

Mesquite juices and gums were used as pigment for hair coloring, tatoo practices, face painting, and as coloring agents for artwork and crafts. Roots and branches were used in the making of twine, trunks for pest- and water-resistant fence posts, beams and supports for homes, for fuel, and for many other uses.

MESQUITE AS AN ORNAMENTAL

A most important feature of mesquite which makes it worthy of landscape consideration for dry regions is its ability to withstand drought. As with many other native desert plants, mesquite has the capability of increasing resistance to water loss as aridity increases (Thomas 1976). *P. glandulosa*, which occurs on much of the rangeland of Texas and other Southwestern states, is a facultative phraetophyte (Hyder 1978). In addition to being able to draw from the water table during extreme drought, this and some other mesquite species are able to drastically reduce their rates of transpiration and to draw tightly held water from the soil when necessary (Thomas 1976).

In addition to its drought resistance, mesquite, with pruning and care can become a very attractive tree or shrub. Its foliage is of good color, soft in appearance, and provides light but effective shade (Fig. 1). Some species are ultimately larger than others. It is known

Figure 1.--Lawn Tree in Lubbock, Texas

that Prosopis velutina is a large tree and the author has seen specimens of P. glandulosa which are forty to sixty feet tall with thirty to forty foot canopy spreads (Fig. 2). Most landscape plantings seen involving any species of mesquite are relatively new plantings, and trees have not yet reached their ultimate dimensions. P. glandulosa while often relatively small in arid and semi-arid wilds, can and does reach impressive sizes after being collected, transplanted and given even minimal care and watering. Among the various species, there are examples which could become valued ornamental shrubs as well as those which would make useful trees.

MARKETING MESQUITE AS AN ORNAMENTAL

The more common negative feelings about mesquite make the suggestion that these species be collected and used as ornamental landscape plants highly repugnant to a large percentage of the people involved in dealing with the plants. Some of the same qualities which make mesquite a pest are the same qualities which could make it a valued dry-land ornamental.

Some nurseries in California, Arizona and Southwest Texas are presently dealing in collected specimens of mesquite which are sold to clients in their respective areas. Other landscape nurserymen could be approached as possible income-producing outlets for salable specimens of mesquite. There are various contractual arrangements by which this can

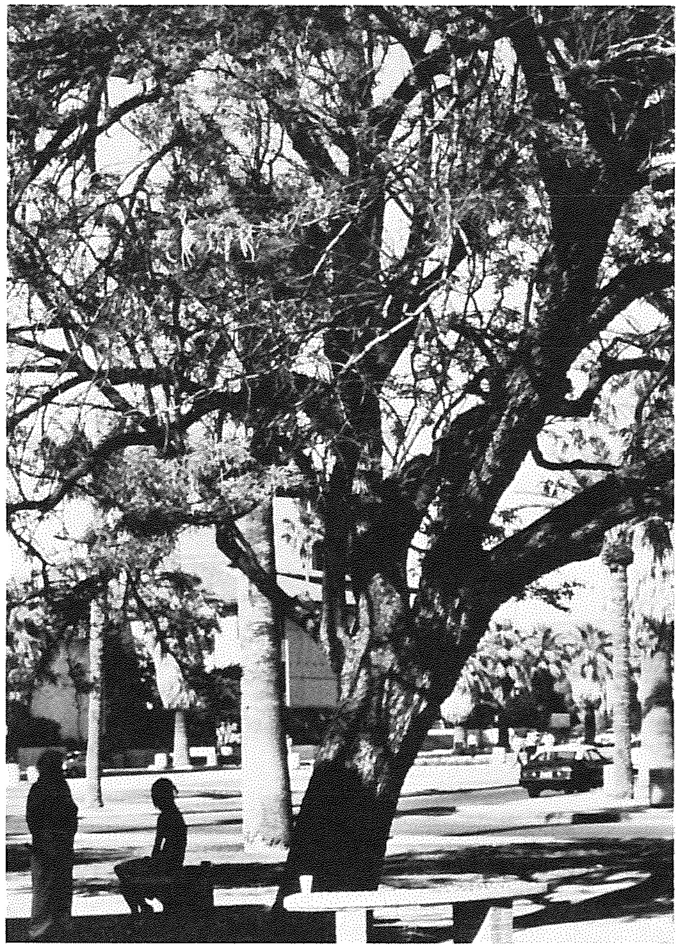

Figure 2.--50 year old Prosopis glandulosa in Tucson, Arizona.

be done. In one case this has been accomplished by leasing a piece of mesquite-infested land to the nurseryman with an appropriate agreement for removal of specimens from the property within an agreed time period. A similar agreement might be reached without the lease. Another, though less efficient possibility might be to allow persons interested in the trees to have direct access to a property for collection of specimens.

Whatever contractual arrangement is worked out, it has been left for the nurseryman to promote the use of mesquite as an ornamental. A nurseryman in El Paso, Texas, who has long used and advocated the use of mesquite for landscaping, began by first planting them in his own yard. These trees, located in a prominant place where they can easily be seen, have been in place for twenty-five years and are forty to fifty feet tall with nearly an equal spread. This businessman's next step was to use mesquite where he could in large contract jobs which he had been hired to design and install. Now, in the El Paso area, large numbers of mesquite trees can be found used effectively in a variety of circumstances. They have been used as individual specimens, as street trees (Fig. 3) for screens, shade, lawn trees (Fig. 4), boundary trees and in tree and shrub groups.

Figure 3.--Young mesquites as street trees in El Paso, Texas.

Figure 4.--Young lawn tree in El Paso, Texas.

An overwhelming demand has not developed, but some customers do come into the nursery and ask specifically for mesquite; some are convinced that mesquite is what they want after they see the established trees in the nurseryman's yard, and others are sold on the trees by the characteristics of the trees, such as light shade, drought resistance, or food production.

MARKET VALUE OF MESQUITE

Currently, collected mesquite with 3" caliper trunks and up are selling in some areas at wholesale prices from $45 to $80 each, with the buyer paying the freight charges. These have been dug with a good-sized ball of earth, lightly pruned, and wrapped to protect the earth ball. The retail nurseryman should expect to sell these trees at prices of from $80 to $160 or more, depending on size, trunk patterns, and costs of moving and planting.

From the Corpus Christi, Texas area, digging and balling should cost from $40 for 2" caliper trees to $115 or more for 4" trees. Freight on plant materials of this size could cost $40 each to Lubbock.

While not all mesquite trees are worthy of being used in landscaping, nor would there be enough space to accommodate them all in ornamental settings, there are many which are large enough and attractive enough to be a valuable resource. Marketing these as ornamentals could be feasible and desirable. Research may need to be done to discover if there are physical limitations to the transplanting of mesquite from wild areas into cultivated landscapes. It is already known that mesquite moved from one area to another tend to retain the timing of leafing out and leaf drop of their original habitat (McMillan and Peacock 1964. Peacock and McMillan 1965). Additionally, the root system of Prosopis glandulosa may spread 22 m laterally and extend to a depth of 53 m (Easter 1973). Work may need to be done to determine if plants would transplant better from wetter areas, where it might be assumed that they would have less extensive root systems than those in dryland areas.

If the rangeland owner could negotiate the sale of 2 attractive mesquite trees per acre on 100 acres of infested property, it would pay for the $12 to $15 per acre cost of spraying to kill brush mesquite on the entire acreage.

Much constructive work can be done by those seeking to rid rangelands of excess mesquite. Tempering the negative press by pointing out and publicizing some of the beneficial uses and characteristics of mesquite should be effective. Active participation in a program to promote the use of mesquite as an ornamental landscape plant could prove to be a positive move which would be of value to everyone involved.

LITERATURE CITED

Easter, S. J. 1973. "Water Relationships of Honey Mesquite". Master's thesis. Texas Tech University.

Hyder, Donald N., ed. 1978. Proceedings of the First International Rangeland Congress. (Denver, Colo., Aug. 14-18, 1978). Society for Range Management, Denver, Colo. 742pp.

Leon-Portilla, M. 1973. Historia naturaly cronica de la antigua California (de Miguel del Barco). Univ. Nac. Autonems de Mexico, Inst. Invest. Hist. de Mexico. Mexico City, Mexico. 464pp.

McMillan, C., and J. T. Peacock. 1964. Bud-bursting in diverse populations of mesquite (*Prosopis*: Leguminosa) under uniform conditions. Southwest. Nat. 9:181-188.

Peacock, J. T., and McMillan. 1965. Ecotypic differentiation in *Prosopis* (mesquite). Ecology 46:35-51.

Simpson, B. B., ed. 1977. *Mesquite Its Biology in Two Desert Scrub Ecosystems*. Stroudsburg, Penn. Dowden, Hutchinson and Ross, Inc. 250pp.

Thomas, Gary Wayne. 1976. "Mesquite Leaf Diffusive Resistance Under Various Environmental Conditions". Master's thesis. Texas Tech University.

UTILIZATION OF MESQUITE IN THE SONORAN DESERT: PAST AND FUTURE

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Abstract.--Mesquite (Prosopis), a nitrogen-fixing desert legume tree, was a major human food resource for millenia. It has a high BTU-to-weight ratio and is prized for lumber, firewood, and cooking fuel. Its development as an arid-land multiple-product crop should have significant effects on conservation of fresh water and energy. Our research focuses on: 1) The history of mesquite in the Sonoran Desert; its uses and recent range expansion. 2) The natural pod productivity and phenology for two species across a broad environmental gradient. 3) A cost-efficient method of inventory for cordage and pod production by Landsat imagery. Cordage and long-term (average) pod production can be determined by Landsat methods on a per unit area basis.

INTRODUCTION

Aside from the saguaro, mesquite is the best known plant in the Sonoran Desert. Mesquite demonstrates that different cultures may view the same resource with different values. Furthermore, values within the same culture may change with time. Ever since humans have been able to manipulate the Sonoran Desert, mesquite has been regarded as a weedy pest. However, others have regarded it as an indispensible resource.

Three species of mesquite occur in the Sonoran Desert: *Prosopis glandulosa* Torr. var. *torreyana* (L. Bens.) M.C. Jtn. (western honey mesquite), *P. velutina* Woot. (velvet mesquite), and *P. articulata* S. Wats. (*mezquite amargo*). *P. articulata* does not produce edible pods. These species are partially segregated by geography and habitat, although there is some hybridization in areas of contact [see Hastings et al (1972) for distributions].

In the first section we discuss the uses and importance of mesquite to the native people. We emphasize the decline of mesquite as a food due to introduced agriculture and changing cultural values and pressures. We also review the historical and ecological evidence of mesquite "invasion" in southern Arizona. A special emphasis is placed on the Altar Valley because it is our Landsat study site. In the second section we present data on phenology and fruit production across a wide range of Sonoran Desert environments and show the importance of multi-year data. In the final section we introduce a cost-efficient technique using Landsat digital data methods to assess firewood and pod yields on a per hectare basis.

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A BRIEF REVIEW OF THE HISTORY OF MESQUITE IN THE SONORAN DESERT

Early Utilization of Mesquite

Mesquite was the staff of life to the native peoples of the Sonoran Desert, as well as other peoples in arid and semi-arid regions of North and South America (Bell and Castetter 1937, D'Antoni and Solbrig 1977, Felger 1977). It was the most important resource, and cultural common denominator, for nomadic hunter-gatherers living in temporary shelters, farmers living in simple rancherías, and even those who lived in fine homes and towns or city empires.

Every part of the plant was utilized, and it figured in everyday life from cradle to grave. Not only was mesquite an important producer of food, it was also a major resource for fuel, shelter, weapons, tools, dyes and paints, medicine, cosmetics, and many other practical and aesthetic purposes (Bean and Saubel 1972, Bell and Castetter 1937, Felger 1977, Gasser 1982, Rea 1978). Since ancient times it has been a preferred cooking fuel.

For hunter-gatherers such as the Seri Indians of Sonora, Mexico, the importance of mesquite is demonstrated by their having names for eight stages of pod development, a term for the seed together with its enclosing endocarp, and another term for the actual seed itself (Felger and Moser 1971). Mesquite phenology and harvesting was significant enough to mark the passing and naming of "moons" or calendar months, for both hunter-gatherers such as the Seri and agriculturalists such as the Pima (Felger and Moser 1971, Rea 1978). For the Pima Indians and others, mesquite was referred to as the tree of life (Rea 1978).

During the golden age of Spanish exploration and discovery, spanning the first one-and-a-half post-Columbian centuries, the newcomers often regarded mesquite as a valuable resource. On occasion it saved their lives (Schroeder and Matson 1965). In Cabeza de Vaca's report on his epic journey of 1528 to 1536 (Bandelier and Bandelier 1905), mesquite became the first plant recorded by Europeans from the American Southwest.

However, with permanent colonization and missionary activity in subsequent centuries, attitudes began to change. Harvesting wild plants and the associated life style was contrary to prevailing 17th century European concepts of proper, civilized society. The Jesuit missions depended on centralized, structured, and settled society based on agriculture and the reducción system (Spicer 1962). Indians camping in the desert, harvesting mesquite, with evenings spent "...singing, dancing, playing games and making love" (Trippel 1889:6-7) were not working in mission fields nor receiving Jesuit instruction and guidance.

Native agricultural crops were summer, or warm weather crops, e.g., corn (maize), beans, squash, and amaranth. There were no important winter-spring agricultural plants. The major, pre-summer or spring harvests were from wild plants: mesquite and other tree legumes such as palo verde (Cercidium spp.); columnar cacti such as saguaro (Carnegiea gigantea), cardón (Pachycereus pringlei), and organ pipe (Stenocereus thurberi); various grains such as saltgrass (Distichlis palmeri) or even eelgrass (Zostera marina), and others (Castetter and Bell 1937, 1942, 1951; Felger and Moser 1974, 1976; Felger et al 1980; Gasser 1982). European introductions, namely wheat, harvested in late spring, provided an alternative to these wild-harvested crops including mesquite (Doelle 1976, Felger 1977).

In any given mesquite population the majority of the pods tend to ripen simultaneously or nearly so. When fully ripe the pods turn light tan. There is considerable variation from population to population, and within populations. Contemporary Gila River Pimans say that pods streaked with red are superior. Nearly all native consultants agree that the best-tasting pods are from trees that yield fatter, larger pods. Sonoran Desert peoples discovered and identified certain trees and local populations having superior flavor and yields, and these special trees or groves were sought out each year (Bean and Saubel 1972, Felger and Moser 1971). However, there is no indication of any attempt at selection or cultivation: the fruit seems to have been generally available far in excess of local needs.

When fully ripe the pods fall, and being rather large and indehiscent, are easily gathered from the ground. On occasion, such as at the beginning of the season, pods were picked directly from the tree (Bean and Saubel 1972). Additionally, the usual time of harvest was often extended several months by robbing packrat (Neotoma) nests. The Seri removed mesquite pods and other fruits and seeds from the nests of the white-throated woodrat (N. albigula) in early fall (Felger and Moser 1976).

The usual method of preparation was to toast or parch the pods to facilitate pounding the mealy pulp (mesocarp) into flour. Preparation was usually done by women, although men might assist them (Felger and Moser 1971). The pods were commonly pounded in bedrock mortars or in large wooden mortars with a large hardwood pestle, often made from ironwood (Olneya tesota, a desert legume). The flour was separated by winnowing and was commonly consumed by mixing or cooking it in water to make atole (porridge). It was also prepared into bread-like cakes by mixing the flour with water and air-drying it; no cooking was necessary. Often the pods were steeped in water, after being cooked and twisted to expose the pulp, to make a sweet, highly esteemed summertime beverage. It was regarded as cooling and refreshing. Sometimes the cooked pods were allowed to ferment into a beer-like beverage. While the preparation of food was almost always done by women, when the pods were fermented it was done by men (Bell and Castetter 1937, Felger and Moser 1971).

At times the protein-rich seeds were also eaten. However, use of the seed does not seem to have been commonplace, at least not in historical times. Special methods were devised to free the seed from the hard, leathery pit (endocarp). After pounding the pods in a bedrock mortar to obtain the sweet pulp the Seri Indians sometimes separated the seed-containing endocarp from the remaining mashed pods by winnowing. Subsequent pounding freed the seeds from the endocarp. The seeds were then toasted and ground on a metate (grinding stone). The ground seeds were often mixed with the sweet mesocarp flour to produce a highly nutritious food (see below). These are only a few of the more common methods by which mesquite was prepared. There were numerous recipes and specialities.

Special metates called gyratory crushers seem to have been made for the implicit purpose of grinding the pods to obtain both mesocarp flour and to free the seeds from the endocarp (Hayden 1967, 1969). Although widespread in the Sonoran Desert region, they are nowhere as abundant or well preserved as in the Pinacate region of northwestern Sonora (Hayden 1967). Little is known of the spatial and temporal distribution of these tools, although they seem to generally date from ancient times. It is unknown why these obviously efficient tools passed out of use. The only other similar stone implements known are from Iran dating six to seven millenia before present (Hole et al 1968). The gryratory crusher is essentially a metate with a hole in the center. By rotating a large pestle with relatively little effort, the mesocarp is converted into flour, and the seeds are separated from the endocarp. The flour and seeds can then readily be separated by winnowing (Felger 1977).

As with most harvests which could be dried, mesquite pods were commonly stored for use throughout the year (Bell and Castetter 1937, Felger 1977). The pods were stored on roof-top granaries, in huge baskets specifically made for the purpose, and in an array of other vessels. The prepared flour and cakes were also stored, sometimes in sealed pottery vessels (Felger 1977).

Recent History of Mesquite in Southern Arizona

During the past one hundred years mesquite densities and distribution in southern Arizona have changed in two major ways. In our opinion mesquite was most abundant in floodplains and along drainageways. Major rivers and streamways had gallery forests consisting of cottonwood, willow, ash, sycamore, and walnut. Dense arborescent mesquite <u>bosques</u> (forest) occurred on adjacent floodplains in an almost unbroken band of varying widths. Almost all of these mesquite bosques have been destroyed by woodcutters and agricultural clearing. Remnants of these great mesquite populations can be seen today in the riparian habitats of the San Pedro and Gila Rivers in southern Arizona (Lowe 1964) and the Rio San Miguel in northern Sonora.

Paradoxically it is certain that there are more shrubby mesquites (primarily P. velutina) in southern Arizona today away from riparian and floodplain habitats than there were 100 years ago (Parker and Martin 1952, Humphrey 1958, Hastings and Turner 1965). Most of this increase has occurred in the desert-grasslands. Three important points on the "mesquite invasion" need to be addressed:

1) The place of mesquite in the desert-grasslands 100 years ago.

2) The effects of recent and long-term climatic change.

3) The role of western man in bringing about recent vegetation changes.

The first point has been addressed generally through historical accounts (Humphrey 1958, Hastings 1959, Hastings and Turner 1965). Unfortunately a careful investigation of the historical records gives no single clear picture, but rather two contradictory ones (Hastings 1959). For example, 100 years ago in south-central Arizona the San Pedro and Santa Cruz drainages have been described as a land of milk and honey or a God-forsaken desert unfit for man or beast; as a fertile grassland or a thorny, venomous wasteland, depending on the time of year and exact location (Hastings 1959).

The desert-grasslands are bordered by desertscrub at lower elevations and by evergreen woodland or interior chaparral at higher elevations. The ecotone between the desert-grassland and desertscrub was often a mesquite-grassland (see Leopold 1950 for a description of mesquite-grassland).

One hundred years ago mesquite densities in desert-grassland might have been controlled by range fires and competition with established grasses (Humphrey 1958, Hastings and Turner 1965). Whereas fire is not necessarily fatal to a mature tree it is deadly to seedlings and small trees up to about five years of age (Hastings and Turner 1965). Heavy grazing by cattle thins grasses and gives mesquite seedlings a chance to become established by reducing competition with the grasses and making range fires less intense. Once established, mesquite is often able to reduce grass cover and further enhance its expansion (Parker and Martin 1952).

Historical and ecological evidence indicates that mesquite was a natural component of the lower elevation of the desert-grasslands, especially in areas of shallow (dry) soils, where the grasses were not as dense (Humphrey 1958, Lowe 1964). As one moved higher in this elevational gradient mesquite became less common but not absent; it persisted in drainages as large isolated trees (Humphrey 1958, John King pers. comm.). Some workers feel that mesquite has not expanded its range in southern Arizona during the last 100 years but has simply become more common within its natural habitat (Fisher 1977, Hastings and Turner 1965, Humphrey 1958).

The role of Europeans in influencing the distribution of mesquite is not clear. One very strong piece of evidence for the importance of Europeans as a catalyst is the fact that changes have followed their settlements, agricultural clearings, and rangeland developments.

Among areas first settled in southern Arizona were the San Pedro and Santa Cruz valleys. During a drought in the early 1890's, one-half to two-thirds of the range cattle died of starvation resulting from overgrazing due to overstocking (Hastings and Turner 1965, Humphrey 1958). Subsequent heavy rains, unrestrained by good ground cover, caused major arroyo cutting. This in turn lowered water-tables adjacent to major streams and drainages, stranding some types of the original vegetation (Cooke and Reeves 1976, Hastings and Turner 1965, Humphrey 1958). Thus, seasonally flooded areas of lush grasses were invaded by arid-adapted vegetation including woody shrubs dominated by mesquite. This phenomenon has been well-documented in the Sonoran Desert (Hastings and Turner 1965, Humphrey 1958).

The Altar Valley, about 60 km west of the Santa Cruz Valley, was settled somewhat later than the San Pedro and Santa Cruz Valleys (fig. 1). The northern portion of the Altar Valley is desertscrub while the southern, high-elevation portion is desert-grassland. The Anvil Ranch is located at the ecotone of desert-grassland and desertscrub. In the early part of this centry the valley bottomland was composed of grasses dominated by waist-high sacaton (*Sporobolus wrightii*) with occasional large mesquites (John King, pers. comm.). The mesquites were infrequent enough to be used as landmarks. Historical photographs and oral history indicate that there was no arroyo (e.g. the present-day channelized Altar-Brawley Wash) through the middle of the valley. During periods of heavy rain the sacaton flats were flooded and became temporary shallow swamps allowing the water to seep into the soil.

After settlement of the valley subsequent events were similar to what occurred 40 years earlier to the east. The cattle from the various homesteads and ranches roamed from the Mexican border at Sasabee to Casa Grande, 160 km to the north. During a drought in the 1930's there was extensive range deterioration from overstocking and subsequent starvation of range cattle. This led to the fencing of land so that stocking could be controlled. The mesquite "invasion," which had hither-to been proceeding at a moderate rate, greatly accelerated.

Arroyo cutting, which began in the late 1800's, also accelerated after the drought (Cooke and Reeves 1976). By 1937 the major drainage in the valley, the Altar Wash, had cut a channel 6 m deep at the Anvil Ranch (Cooke and Reeves 1976). Much of this channel is coincidental with the old wagon road to Sasabee. Today, similar but smaller scale channelization occurs in most dirt roads in the valley that lack water spreaders.

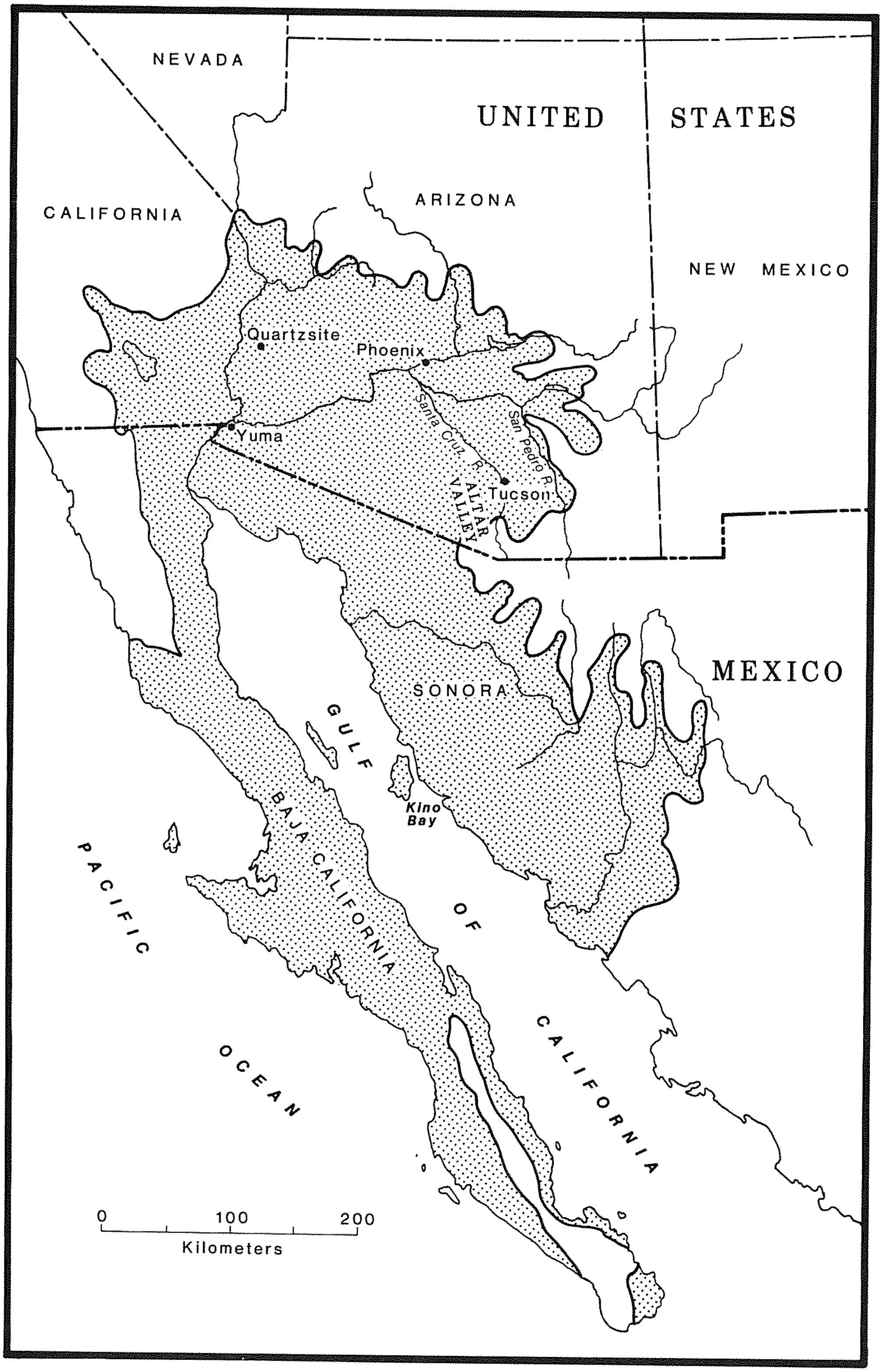

Figure 1. The Sonoran Desert.

Early homesteading practices also helped mesquite establishment with agricultural clearing destroying grasses (primarily sacaton) in the bottomland. Frequently the homesteads were abandonded and the bare fields colonized by mesquite. Today, large areas in the northern part of the valley are choked with shrubby "invasion" mesquite. Moving up the elevational gradient southward in the Altar Valley, mesquite becomes less common on the interfluves and is more abundant in the drainages. Mesquite's propensity for desert-grassland arroyos is probably due more to the ability to colonize disturbed habitat than the need for the additional water.

So far we see western man as the primary agent in recent vegetational changes through over-grazing, agriculture, and road building. However, there is other evidence suggesting that the southern Arizona climate has been changing and man is an unwitting accomplice exacerbating vegetation changes that would be expected during a trend towards greater aridity (Hastings and Turner 1965, Humphrey 1958).

Indeed, we can say with confidence that there has been a trend towards greater aridity since about 8,000 to 10,000 years ago with evidence from fossil floras (Axelrod 1979), fossil pollen (Martin 1963), and packrat middens (Van Devender 1977, Van Devender and Spaulding 1979). The post-Columbian re-introduction of megafauna (e.g., cattle and horses) has resulted in an increase of the spread of mesquite seeds. Mesquite has seemingly co-evolved sweet pods for megafaunal dispersal (Janzen and Martin 1982, D. Janzen pers. comm.). Not since the Pleistocene have there been so many megafaunal seed vectors in the Sonoran Desert (Martin 1963).

In the long run, mesquite and the desert in general seem to be expanding at the expense of the desert-grassland as a result of natural climatic change as well as the agency of man (Hastings and Turner 1965). If natural climatic trends are an important factor in desertification then extreme caution must be utilized when drastic methods (widespread removal of mesquite) are employed to make things "like they were in the good old days." As one of the largest and by far the most abundant nitrogen-fixing plants in the Sonoran Desert, its importance to the ecosystem should not be underestimated. The problem of reversing the recent trends in desertification are further compounded by the loss of soil by heavy erosion. Removal of mesquite without successful introduction of grasses would greatly intensify the problem.

PHENOLOGY AND FRUIT PRODUCTION

During a six year period (1976-1981) mesquite trees across the Sonoran Desert were monitored yearly. Phenology and fruit production data were collected from 60 marked trees. Phenology data were also gathered from other populations. Three study sites for velvet mesquite were located in southern Arizona and two study sites for western honey mesquite in western Arizona and Sonora (fig. 1):

Locations and Species	Elevation (m)	Annual Precipitation (mm)
P. velutina		
Tucson	730	280
Green Valley (45 km S. of Tucson)	915	320 (at Amado)
Kitt Peak area (55 km W. of Tucson)	915	280 (at Anvil Ranch)
P. glandulosa torreyana		
Quartzsite area	270	111
Kino Bay area (10 km N. of Kino Bay)	50	--

[See Sellers and Hill (1974) for climatic data and station locations]

Phenology

In the Tucson area mesquite generally leafs out in March, flowers in April and May, produces fruit in late May and June, and the fruit ripens in late June and July. The fruit on any one tree or population tends to ripen simultaneously. This scheme can be altered several ways. If the trees begin to flower and the weather turns cold and rainy, flowering will stop until it becomes warmer. In this way flowering and fruiting are mixed on one tree; all of the fruit do not ripen simultaneously and the fruit maturation runs through late July and into August (see Mooney et al 1977). In addition, the flowering begins earlier in warmer areas such as at lower elevation, lower latitude, and in warmer microhabitats. Within an area, phenological differences, which can be as great as two weeks for trees flowering in the spring, seem to be due to microhabitat differences rather than day length.

During most years, especially dry ones, many trees in drier microhabitats do not flower during the spring. Most of these trees flower after the onset of the summer rains, usually in late July. This phenomenon might be responsible for the belief that mesquite can fruit twice a year. To our knowledge there is no mesquite tree in this area that has flowered and fruited normally in the spring that has done so again in the summer. Mesquite trees that flower and fruit with the summer rains can have mature fruit on them as late as October.

Not all mesquite trees produce fruit yearly. Sometimes entire areas have little fruit production such as Kino Bay in 1979 and the Tucson area in 1978 due to a severe freeze (see Nabhan et al 1979). However, if the failure is not due to widespread late or extreme freezing weather the situation is usually localized and other productive populations or individuals can often be found. Nectar flow is also adversely affected by freezing, cool and wet spring weather, and dry years (Robert Schmalzel pers. comm.).

Fruit Production

Most sites were established without detailed knowledge of fruit production of the trees. The exceptions are Green Valley and Kino Bay. The Green Valley population is located on the edge of a pecan orchard and receives irrigation runoff. The Kino Bay population is part of a traditional mesquite-pod collecting area for the Seri Indians (Felger and Moser 1971). The remaining sites were chosen as to represent "average" mesquite populations. However, we do not have population samples that represent the great mesquite <u>bosques</u> making up the gallery forests of major Sonoran Desert drainages because these are now mostly destroyed.

All of the trees in the fruit production study were marked with metal tags around the trunk. Crown measurements (height and width) were taken. Every year the fruit on each tree were counted. Generally little estimating took place unless the pods were too crowded. Whenever possible a sample of the mature fruit was collected and pod and seeds weighed.

In most of the sites there is a significant correlation between crown diameter and the number of pods produced. In those areas where there is not a good correlation, the correlation becomes better when multi-year data are used. Multi-year data are the mean pod production of an individual tree over two or more years. Variance in year to year pod production is not only due to the temperature and rainfall during the months previous to flowering, but also to the history of the tree. For example, if a tree has low pod production one year, it will most likely have high production the following year.

Multi-year data smooth out the effects due to history. Multi-year data pooled from three Sonoran Desert localities show a very high correlation between crown diameter and mean pod productivity ($p < 0.001$, fig. 2). In other words, it matters not whether the tree is <u>P. velutina</u> or <u>P. glandulosa</u>, or whether it occurs in an area with 111 or 280 mm annual rainfall, the same equation will predict the long term (average) fruit production using only the crown diameter of the tree.

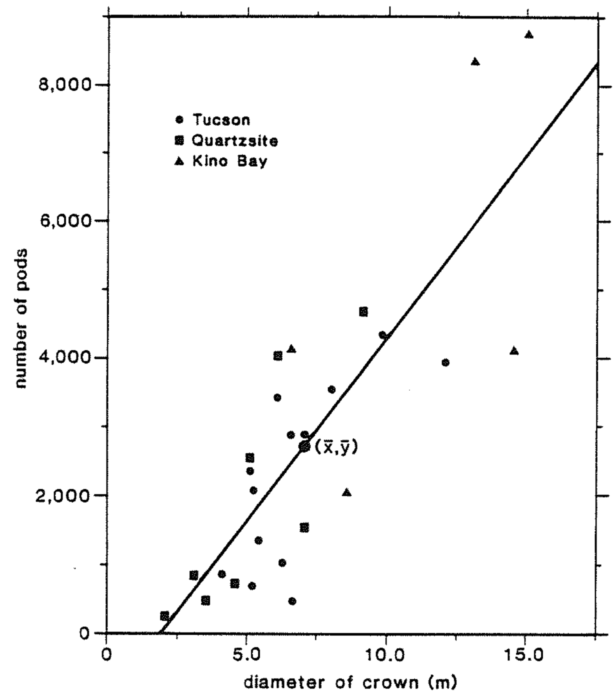

Figure 2. Multi-year (mean) pod productivity against mesquite crown diameter ($y = 539.44x - 1033.57$, $n = 26$, $r = 0.823$)

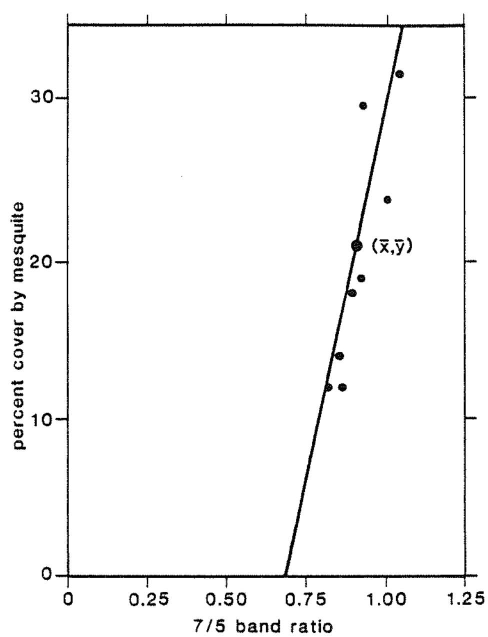

Figure 3. Percent total cover of mesquite against 7/5 band ratio.

An important difference between P. velutina and P. glandulosa is the percent of the pod that is seed (30% for P. velutina and 20% for P. glandulosa var. torreyana). This is particularly important since the protein content of the seed is much higher than that of the pod. Protein content ranges from 32 to 39% in the seed (Jones and Earle 1966, Nabhan et al 1979) as compared to the pod (mesocarp) which has 5.8 to 8.1% (Felker and Bandurski 1979, Nabhan et al 1979).

P. velutina and P. glandulosa also seem to have different soil and temperature preferences, but there appears to be hybridization and introgression in areas of contact. Hybridization also occurs among the South American species (Hunziker et al 1975).

MESQUITE INVENTORY BY LANDSAT DIGITAL DATA: THE ALTAR VALLEY

The Altar Valley is located about 80 km west of Tucson (fig. 1). The dominant vegetation of the northern half of the valley is Sonoran Desert Scrub while the vegetation of the more elevated southern end is Semidesert Grassland. Climatic data at the three study sites are given below (Sellers and Hill 1974):

	Mean annual precipitation (mm)	Annual mean daily max. temp. (°C)	Annual mean daily min. temp. (°C)	Elev. (m)
Sonoran Desert Scrub:				
Anvil Ranch	271	29.1	9.1	838
Semidesert Grassland:				
Fresnal Ranch	500	26.5	10.2	1128
Sasabee	428	26.2	9.4	1094

At higher elevations the Semidesert Grassland grades into Oak Woodland. A description of land-use and the increase of mesquite in the Altar Valley is discussed above.

The Arizona State Land Department is inventorying the resource base of state owned land, and considering mesquite as a renewable resource for firewood, pods, and honey. However, standard methods of biomass estimation are not cost-efficient.

In 1980, the University of Arizona, Office of Arid Lands Studies, Applied Remote Sensing Program contracted to develop a cost-efficient technique for mapping mesquite and estimating cordage on state lands using Landsat digital data. Landsat data were chosen from 30 June 1977, to coincide with the height of the dry season. At this time mesquite is in full foliage and by far the dominant green plant (actively photosynthesizing) and is spectrally distinct. Percent cover by mesquite was calculated using a ratio of the 7 (reflective infrared) and 5 (red) spectral bands.

The correlation betwen the 7/5 ratio and percent mesquite cover was calculated using ground verification data. Field data were accumulated from eight sites. The site means for percent cover were regressed against the mean 7/5 ratio values for the pixels corresponding to the site and the resulting coefficients used to convert ratio values to cover values (Hutchinson et al 1982). Cover values also showed a strong correlation to average crown diameters. When the mesquite is divided into two ecological (growth) classes, riparian and nonriparian, there is a significant correlation between crown diameter and estimated cordage using recently developed field methods (Arizona State Land Department 1978). The methodology for field estimates of cover and cordage is described below.

Ground Verification

Extensive ground sampling is economically inefficient for a mesquite inventory. Far less ground sampling is required for calibration of Landsat data to vegetation parameters such as cover. The method used here is composed of two phases:

1) Vegetation stratification with aerial photography to select ground sampling sites, and

2) Field sampling to estimate percent cover.

The purpose of the first phase is to ensure that the full range of mesquite cover densities is sampled. It is desirable that the aerial photography be as close to the date of Landsat coverage as possible. In addition, sample sites can be selected for accessibility to roads and trails to minimize field time. Both high-altitude, 1:120,000 scale color infrared photography and 1:62,500 scale black-and-white orthophotoquad coverage were used. The high altitude infrared photography was the more useful in evaluating cover classes since the infrared response from vegetation more clearly depicts the degree of cover. Image elements of texture, tone, and pattern were used to identify cover classes, e.g., dense riparian vegetation, moderately dense thickets in upland settings, and sparse vegetation in lowland settings. Of the field sites available for each class, eight were selected to represent the range of vegetation cover density in a topographic cross-section.

At each of the field sites, six 50 m line transects were randomly placed. All species that fell on, over, or under a steel tape were recorded, as well as the length of transect covered by each species and the amount of overlap where plants covered one another [see Mueller-Dombois and Ellenberg (1974) for a description of the line-intercept technique].

For each field site, a 50 by 50 m quadrat (0.25 ha) was established along the transect. Within each quadrat all mesquite trees were measured for height, canopy diameter, and stump diameter at 25 cm above ground level.

Cover Calculation and Cordage Estimation

For each site, average percent cover for each species and total percent cover for all species was calculated from the transect measurements. From the quadrat measurements, a value for mesquite canopy cover was calculated and compared for consistency with the value estimated from the transects.

Field site cover estimates were compared with Landsat multispectral scanner (MSS) band 7/5 ratio values after locating the corresponding picture element (pixel) for each field site. Coordinates of the training pixels were used to extract band brightness values from the digital image. A linear regression of percent cover data (y) against 7/5 ratio data (x) yielded the following prediction equation (fig. 3):

$$y = 87.388(x) - 59.344$$

This is a very significantly correlated relationship ($p < 0.01$).

The methods used to calculate cordage were derived from guidelines of the Arizona State Land Department, Forestry Division (Arizona State Land Department 1978):

stem area x height x taper factor = volume/stem (cubic feet)

summation of stem volumes/128 cubic feet = solid cords/area

solid cords/air space factor = stacked cords/area sampled

Only trees with a trunk diameter of at least 15 cm were used in the merchantable cordage calculations. For these calculations, a taper factor of 0.6 and an air space factor of 0.8 were used as constants (Carl Jones, pers. comm.).

Predictably higher values of stacked cords/ha were obtained for riparian-situated mesquite than for either lowland or upland mesquite (for stands of mesquite with similar canopy cover). The consistency of these results, based on a sample of 272 trees, led to the derivation of a two-way transformation of cover to cordage, dependent upon the landform setting:

Riparian setting:

$$\frac{\dfrac{\%\ \text{mesquite cover}}{100} + 0.0905}{0.0348} = \frac{\#\ \text{stacked cords}}{\text{ha}}$$

Non-riparian setting:

$$\frac{\dfrac{\%\ \text{mesquite cover}}{100} - 0.0775}{0.0345} = \frac{\#\ \text{stacked cords}}{\text{ha}}$$

CONCLUSIONS: THE FUTURE

Throughout its association with humans mesquite has been an important plant, sometimes viewed as a valuable resource and at other times as a tenacious, range-deteriorating pest. In the past a great deal of time and energy has been spent in attempts to eradicate mesquite. Often this approach has not taken into account its value as a renewable resource.

The future of mesquite may be as a managed or agricultural multiple product crop yielding a valuable source of nutrition and biomass adapted to arid and disturbed habitats. Certain species and taxa of mesquite, in the section Algarobia of the genus Prosopis, have considerable agronomic potential (Felger 1979, Felger and Nabhan 1978, Felger et al 1981, Felker 1979, National Academy of Sciences 1979, Smith 1953). Mesquite's credentials as an arid land crop are impressive: drought surviving, salt resistant, nitrogen fixing, highly nutritious fruit and seeds, high hybridization potentials, and valuable firewood, just to mention a few of the more obvious attributes.

For example, using data from natural populations of mesquite we estimate that a mature orchard with 118 trees/ha with crowns of 8 m in diameter can be expected to yield 2300 kg of pods/ha/year, with little or no input of water and fertilizer (Felger et al 1981). This is comparable to yields of other modern agricultural crops. By hybridization, selection, cloning, fertilization, and drip-irrigation mesquite could become an important food crop in arid lands around the world.

Even today mesquite is of great value as a fuelwood. In early 1982, one cord of mesquite sold for $35 per cord on the stump (uncut) as compared to $7 to $9 for pinyon and juniper. From our study sites in the Altar Valley the average percent cover by mesquite is 20.1%. Therefore, a riparian habitat would yield 8.4 harvestable cords of wood per hectare or $294 and a non-riparian habitat would yield 3.6 cords or $126 worth of firewood.

Not only can we calculate mesquite cordage and densities by Landsat methods, but it is possible that long term (average) pod production can also be predicted. We have demonstrated that Landsat methods can detect percent mesquite cover from which the average crown diameter can be calculated (in the Altar Valley). In the discussion on fruit production (above) it was demonstrated that a single equation is sufficient to predict fruit productivity from crown diameter. This was shown for populations of two species in three widely dispersed and environmentally different localities in the Sonoran Desert when multi-year data are used (fig. 2). Our data indicate that this technique is valid throughout the Sonoran Desert. This methodology should be applicable to other species in different habitats and other parts of the world.

In this paper we have demonstrated that it is possible to use cost-efficient Landsat digital data methods to calculate cordage and pod production per hectare. This method might also be used to monitor changes in mesquite densities and distributions. This could lead to the development of a powerful tool to land managers who must make cost-benefit decisions.

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LITERATURE CITED

Arizona State Land Department. 1978. A fuelwood inventory of mesquite for the San Pedro River of Cochise County and the establishment of a fuelwood inventory method for mesquite. Arizona Land Marks 9:7.

Axelrod, D.I. 1979. Age and origin of Sonoran Desert vegetation. California Academy Science, Occasional Papers No. 132. 74 p.

Bandelier, A., and F. Bandelier. 1905. The journey of Alvar Nuñez Cabeza de Vaca and his companions from Florida to the Pacific 1528-1536. A.S. Barns, New York. 231 p.

Bean, L.J., and K.S. Saubel. 1972. Temalpakh. Malki Museum Press. Banning, California. 225 p.

Bell, W.H., and E.F. Castetter. 1937. Ethnobiological studies in the American Southwest V. The utilization of mesquite and screwbean by the aborigines in the American Southwest. University of New Mexico Biological Series 5(2):1-55.

Castetter, E.F., and W.H. Bell. 1937. The aboriginal utilization of the tall cacti in the American southwest. University of New Mexico Bulletin 307. Ethnobotanical Studies in the American Southwest 5(1). 48 p.

-----. 1942. Pima and Papago Indian Agriculture. University of New Mexico Press, Albuquerque. 245 p.

-----. 1951. Yuman Indian agriculture. University of New Mexico Press, Albuquerque. 274 p.

Cooke, R.V., and R.W. Reeves. 1976. Arroyos and environmental change in the American Southwest. Clarendon Press, Oxford. 213 p.

D'Antoni, H.L., and O.T. Solbrig. 1977. Algarrobos in South American cultures past and present. p. 189-199. In B.B. Simpson, Ed. Mesquite. Dowden, Hutchinson and Ross, Stroudsberg, Pennsylvania. 250 p.

Doelle, W.H. 1976. Desert resources and Hohokam subsistence: the Conoco Florence project. Arizona State Museum Archaeological Series No. 103. 278 p.

Felger, R.S. 1977. Mesquite in Indian cultures of southwestern North America. p. 150-176. In B.B. Simpson, Ed. Mesquite. Dowden, Hutchinson and Ross, Stroudsberg. 250 p.

-----. 1979. Ancient crops for the twenty-first century. p. 5-20. In G.A. Ritchie, Ed. New Agricultural Crops. Westview Press, Boulder, Colorado. 259 p.

Felger, R.S., L.S. Leigh, S.L. Buchmann, D.O. Cornejo, M.A. Dimmitt, D. Johnson Gordon, C. Nagel, L. Ratener, and C.A. Stigers. 1981. Inventorying the world's arid lands for new crops: a model from the Sonoran Desert. p. 106-116. In H.G. Lund, Ed. Proceedings of arid lands resource inventories workshop. USDA Forest Service General Technical Report WO-28.

Felger, R.S., and M.B. Moser. 1971. Seri use of mesquite (*Prosopis glandulosa* var *torreyana*). The Kiva 37:53-60.

-----. 1974. Columnar cacti in Seri culture. The Kiva 39:257-356.

-----. 1976. Seri Indian food plants: desert subsistence without agriculture. Ecology of Food and Nutrition 5:13-27.

Felger, R.S., M.B. Moser, and E.W. Moser. 1980. Seagrasses in Seri Indian culture. p. 260-276. In: R. Phillips and C.P. McRoy, Eds. Handbook of seagrass biology: an ecosystem perspective. Garland STPM Press.

Felger, R.S., and G.P. Nabhan. 1978. Agroecosystem diversity: a model from the Sonoran Desert. p. 129-149. In N. Gonzales, Ed. Social and technological management in dry lands: past and present, indigenous and imposed.

Felker, P. 1979. Mesquite: An all-purpose Leguminous arid land tree. p. 89-132. In G.A. Ritchie, Ed. New Agricultural Crops. Westview Press, Boulder. 259 p.

Felker, P., and R.S. Bandurski. 1979. Uses and potential uses of leguminous trees for minimal energy input agriculture. Economic Botany 33(2):172-184.

Fisher, C.E. 1977. Mesquite and Modern man in southwestern North America. p. 177-188. In B.B. Simpson, Ed. Mesquite. Dowden, Hutchinson and Ross, Stroudsberg. 250 p.

Gasser, R. 1982. Hohokam use of desert food plants. Desert Plants 2(4):216-234.

Hastings, J.R. 1959. Vegetational change and arroyo cutting in southeastern Arizona. Journal of the Arizona Academy of Sciences 1:60-67.

Hastings, J.R. and R.M. Turner. 1965. The changing mile: an ecological study of vegetation change with time in the lower mile of an arid and semi-arid region. University of Arizona Press, Tucson. 317 p.

Hastings, J.R., R.M. Turner, and D.K. Warren. 1972. An atlas of some plant distributions in the Sonoran Desert. University of Arizona, Institute of Atmospheric Physics, Technical Reports on the Meteorology and Climatology af Arid Region No. 21. 255 p.

Hayden, J.D. 1967. A summary prehistory and history of the Sierra Pinacate, Sonora. American Antiquity 32:335-344.

-----. 1969. Gyratory crushers of the Sierra Pinacate, Sonora. American Antiquity 34:154-161.

Hole, F., F.V. Flannery, and J.A. Neeley. 1969. Prehistory and human ecology of the Deh Luran Plain: an early village sequence from Khuzistan, Iran. Mus. Anthropol. Univ. Mich., Ann Arbor, Memoir I. 504 p.

Humphrey, R.R. 1958. The Desert Grassland: A History of Vegetational Change and an Analysis of Causes. Botanical Review 24(4):193-252.

Hunziker, J.H., L. Poggio, C.A. Naranjo, R.A. Palacios, and A.B. Andrade. 1975. Cytogenetics of some species and natural hybrids in Prosopis (Leguminosae). Canadian Journal Genetics and Cytology 17(2):253-262.

Hutchinson, C.F., L.S. Leigh, and M.C. Parton. 1982. Mesquite Cordage Mapping from Landsat Digital Data: Altar Valley, Arizona. Report to Arizona State Land Department, Forestry Division.

Janzen, D.H. and P.S. Martin. 1982. Neotropical anachronisms: the fruit the gomphotheres ate. Science 215:19-27.

Jones, Q., and F.R. Earle. 1966. Chemical analyses of seeds II: Oil and protein content of 759 species. Economic Botany 20:127-155.

Leopold, A.S. 1950. Vegetation zones of Mexico. Ecology 31(4):507-518.

Lowe, C.H. 1964. Arizona Natural Environment. University of Arizona Press, Tucson. 136 p.

Martin, P.S. 1963. The last 10,000 years. University of Arizona Press, Tucson. 87 p.

Mooney, H.A., B.B. Simpson, and O.T. Solbrig. 1977. Phenology, Morphology and Physiology. p. 26-43. In: B.B. Simpson, Ed. Mesquite. Dowden, Hutchinson and Ross, Stroudsberg. 250 p.

Mueller-Dombois, D., and H. Ellenburg. 1974. Aims and methods of vegetation ecology. Wiley, New York.

Nabhan, G.P., C.W. Weber, and T.W. Berry. 1979. Legumes in the Papago-Pima Indian diet and ecological niche. The Kiva 44(2-3):173-190.

National Academy of Sciences. 1979. Tropical legumes: resources for the future. National Academy of Sciences, Washington DC. 331 p.

Parker, K.W., and S.C. Martin. 1952. The mesquite problem on southern Arizona ranges. U.S.D.A., Circular 908. 70 p.

Rea, A. 1978. Velvet mesquite. Environment Southwest No. 486.

Schroeder, A.H., and D.S. Matson. 1965. A colony on the move, Caspar Castaño de Sosa's Journal 1590-1591. School of American Research, Salt Lake City. 196 p.

Sellers, W.D. and R.H. Hill. 1974. Arizona Climate: 1931-1972. University of Arizona Press, Tucson. 616 p.

Smith, J.R. 1953. Tree crops -- a permanent agriculture. Devin-Adair Publishing Company, New York.

Spicer, E.H. 1962. Cycles of Conquest. University of Arizona Press, Tucson. 609 p.

Trippel, E.J. 1889. The Yuma Indians. Overland Monthly Series 2, 13:561-584 and 14:1-11.

Van Devender, T.R. 1979. Holocene woodland in the Southwestern Deserts. Science 198:189-192.

Van Devender, T.R. and W.G. Spaulding. 1979. Development of vegetation and climate in the Southwestern United States. Science 204:701-710.

SYMBIOTIC NITROGEN FIXATION BY MESQUITE AND ITS MANAGEMENT IMPLICATIONS[1]

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Sonoran Desert mesquite woodlands have very high biomass and productivity relative to other desert plant communities and fix significant amounts of nitrogen. Glasshouse experiments show that mesquite growth can be enhanced by inoculation with effective rhizobia and that the symbiosis is relatively insensitive to combined nitrogen. Chilean plantations are nodulated and their productivity may be phosphorus limited. During the selection of high biomass producing genotypes and the development of specific cultural practices for mesquite, nitrogen fixation capability should be a central consideration.

INTRODUCTION

Woody legumes (species of *Prosopis*, *Cercidium*, *Acacia*) form a major part of the biomass in arid and semi-arid ecosystems throughout the world. In the deserts of the southwestern United States mesquite (*Prosopis glandulosa*) occurs on about 30 million ha (Parker and Martin 1952). In some rangeland areas mesquite is invasive and major efforts have been undertaken to control its distribution (Fisher et al. 1973). Recently, however, mesquite has been recognized as a potentially important source of biomass-derived energy, firewood, and forage (Felker 1979; NAS 1975, 1979).

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Few data are available on the biomass and productivity of native mesquite woodlands. The significance of symbiotic N_2-fixation by mesquite and the impact of this fixed N on mesquite productivity is poorly understood. We are reporting results of an ecosystem level study of nitrogen cycling, productivity, and water use by mesquite woodlands. Nutrient content and productivity measurements from managed Chilean stands are also presented. From this data base the management implications of nitrogen fixation by mesquite will be discussed.

BIOMASS AND PRODUCTIVITY

Information about the productivity of native mesquite woodlands is useful as a baseline for evaluating the productivity of intensively managed stands. We measured biomass and net primary production of a phreatophytic mesquite (*Prosopis glandulosa* var. *torreyana*) woodland growing near Harper's Well, California using dimensional analysis techniques (Sharifi et al. 1982). Biomass and productivity were highest near the wash, where groundwater is available year round at 4-6m depth, and decreased at the stand fringe as the depth to groundwater increased (table 1). This level of biomass and production far exceeds that of other North American desert communities (Szarek 1979) including two other *Prosopis* communities (Klemmedson and Barth 1975). About half of the above-ground productivity was new woody tissue for pre-existing branches and trunks. Pod production varied considerably between the two years and was 39% higher in 1981. Pod production is most likely cyclic, depending on pod production the previous year and on weather conditions during the critical pollination period.

Table 1.--Above-ground biomass and net primary production of a mesquite woodland at Harper's Well.

	Mesquite Cover %	Biomass kg ha^{-1}	Productivity kg ha^{-1} yr^{-1}
Near Wash	48	21,703	5,655
Stand Fringe	29	3,448	898
Largest Value	77	30,614	7,973
Stand Mean	33	13,973	3,635

Relatively large amounts of N are required to support the productivity measured at Harper's Well (table 2). The N content of leaves, flowers, and pods was about 60 kg ha^{-1} yr^{-1}. Extrapolating to a dense stand such as plantation (80% cover) nearly 150 kg N ha^{-1} yr^{-1} would be harvested or lost as litter from the trees. Some of this N would be recovered by translocation of N from senescing leaves and from decomposition of litter. Nonetheless, a large N input either from N_2-fixation or fertilization will be required to maintain high production in managed stands. This will be particularly true for high pod-producing genotypes.

Table 2.--Above-ground stand productivity and N content of a mequite woodland at Harper's Well for 1980 and 1981. Mesquite cover is 33%.

	Productivity ($kg\ ha^{-1}\ yr^{-1}$)		Nitrogen in Productivity ($kg\ ha^{-1}$)	
	1980	1981	1980	1981
Woody Increment	1861	1861	11.6	11.6
New Twigs	124	101	1.9	1.8
Leaves	1207	879	33.4	25.6
Flowers	145	507	3.7	16.3
Pods	763	1251	14.5	30.1
Total	3635	4462	65.1	85.3

MEASUREMENTS OF N_2-FIXATION BY MESQUITE

The acetylene reduction assay for nitrogenase activity has become a routine method for estimating N_2-fixation activity under controlled conditions (e.g. Turner and Gibson 1980). This method can be applied to field settings if: 1) direct recovery of a representative sample of nodules is possible, 2) the nodule mass per unit area is known, 3) acetylene can be introduced around the entire root system and the evolved ethylene recovered (Knowles 1980). Even if these conditions are met, seasonal and diurnal fluctuations in acetylene reduction activity and the problem of quantitatively relating acetylene reduced to atmospheric N_2 fixed make this approach difficult.

We are applying a different method to estimate N_2-fixation in mesquite communities based on measurements of natural ^{15}N abundance. Since the ^{15}N abundance of soil N is often higher than that of atmospheric N_2 (Shearer et al. 1978), N_2-fixing plants usually have a lower ^{15}N abundance than associated non-N_2-fixing plants (Shearer and Kohl 1978, Virginia and Delwiche 1982). The magnitude of this difference in ^{15}N abundance between the fixing and non-fixing plants is proportional to the amount of N_2 fixed by the nodulated plant (Amarger et al. 1979, Kohl et al. 1980). We have estimated the fractional contribution of N_2-fixation to several mesquite woodlands by measuring the ^{15}N content of mesquite relative to associated non-N_2-fixing plants and soil N (Shearer et al. in press).

The ^{15}N abundance of mesquite growing at seven Sonoran Desert sites is presented in table 3. With the exception of one site (Baja, Catavina) mesquite had significantly lower ^{15}N abundance than the associated non-N_2-fixing control plants. We estimated that approximately 50% of mesquite's N requirement came from N_2-fixation at these sites. The apparent lack of N_2-fixation at the Catavina site indicates N_2-fixation by mesquite is not ubiquitous and that site characteristics (soil type, moisture regime) and stand age may limit nodulation or fixation. These N_2-fixation estimates should be considered semi-quantitative since within plant variation in ^{15}N abundance occurs (Shearer et al. 1980) and isotopic fractionation during N uptake by roots varies slightly with species (Mariotti et al. 1980, Kohl and Shearer 1980).

Table 3.--Natural ^{15}N abundance ($\delta^{15}N$[1]) of leaf tissues from mesquite (Prosopis glandulosa var. torreyana) and associated non-N_2-fixing control plants and the estimated fractional contribution of N_2-fixation to mesquite for sites in the Sonoran Desert. Values in parentheses are standard errors of the mean, n = number of specimens.

Site	Mesquite n	Mesquite $\delta^{15}N$	Control Plants n	Control Plants $\delta^{15}N$	% N Fixed[2]
Harper's Well	40	1.2 (0.2)***	12	5.1 (0.5)	61 (7)
Harper's Well Transect	9	1.1 (0.5)*	15	3.0 (0.6)	43 (15)
Nude Wash	1	1.2	19	5.7 (0.3)	65
Borrego Sink	3	2.0 (0.2)**	5	6.9 (0.7)	60 (5)
Carizzo Badlands	2	2.2 (0.2)**	4	6.6 (0.6)	57 (6)
Clark Dry Lake	3	4.7 (0.7)***	4	13.0 (0.4)	58 (5)
Baja, Catavina	5	8.9 (0.3)	13	9.3 (0.6)	1 (5)

1

$$\delta^{15}N = \frac{\text{atom \% }^{15}N\text{ sample} - \text{atom \% }^{15}N\text{ atmospheric }N_2}{\text{atom \% }^{15}N\text{ atmospheric }N_2} \cdot 1000$$

2

$$\%N\text{ Fixed} = \frac{x-y}{x-f} \cdot 100$$ where $x = \delta^{15}N$ of control plants,

$y = \delta^{15}N$ of Prosopis, $f = \delta^{15}N$ of Prosopis grown in solution culture without added N.

*, **, *** indicate difference between Prosopis and control plant significant at the 0.05, 0.01, and 0.001 levels, respectively by t-test.

At Harper's Well we have detailed measurements of productivity (Sharifi et al. 1982) and N dynamics (Rundel et al. 1982, Virginia et al. 1982). Nitrogen uptake from soil and N_2-fixation together were 17 and 23 g N m^{-2} canopy area in 1980 and 1981, respectively. Assuming 60% of this amount came from fixation (table 3), on a stand basis (33% mesquite cover) symbiotic N_2-fixation provided an input of 35 kg N/ha in 1980 and 47 kg N/ha in 1981 to the above-ground portion of this ecosystem. Under managed situations much higher N_2-fixation rates should be possible as stand cover would be considerably higher.

THE MESQUITE-RHIZOBIUM SYMBIOSIS

The capability of Prosopis spp. to fix N_2 has been demonstrated in glasshouse studies (Bailey 1976, Felker and Clark 1980) but reports of nodule recovery from the field are few (Allen and Allen 1981, Pepper et al. 1980, Virginia et al. 1982). Mesquite can be effectively nodulated by rhizobia from some other mimosoid woody legumes (Allen and Allen 1981). Mesquite rhibozia appear to fall in the cowpea miscellaney group and can be very salt tolerant, growing at 3% NaCl in culture (Hua 1981).

The yield of most legume crops can be increased by inoculation with selected rhizobia. The formation of an effective mesquite-Rhizobium symbiosis is essential if N fertilizer inputs to managed stands are to be kept to a minimum. We tested four rhizobia strains isolated from mesquite (WR1001, WR1002, L5, L9) and one from cowpea (Vigna unguiculata, 176A32) on mesquite seedlings growing without added N (table 4). Acetylene reduction activity and H_2 evolution of intact root systems were measured to determine if these strains had an uptake hydrogenase lowering the energy requirement for N_2-fixation (Schubert and Evans, 1976). Strain WR1002 (isolated from a field recovered nodule at Harper's Well) failed to nodulate mesquite in this trial but has proved to be an effective N_2-fixing strain in other experiments. Strain L5, isolated from an ineffective nodule, was ineffective in this experiment. L5 nodules were small and had a large number of amyloplasts in the cortical cells. The high relative N_2-fixing efficiences of L9 and 176A32 indicate these strains have an uptake hydrogenase system. Interestingly, the cowpea strain had the highest plant yield and the highest relative efficiency, yet the lowest acetylene reduction activity. Results from these few strains indicate mesquite seedling growth can be improved by selection of the appropriate rhizobia. Field trials are needed to determine if superior strains will be competitive with native rhizobia, and whether yields can be improved over longer periods of time.

MESQUITE RESPONSE TO ADDED NITROGEN

The legume-Rhizobium symbiosis is sensitive to the presence of inorganic N. Relatively low concentrations of inorganic N in the soil solution can inhibit nodulation and nodule function (Pate 1977). We added 4 levels of NO_3-N to nodulated mesquite (*Prosopis glandulosa* var. *torreyana*) plants to determine the sensitivity of the mesquite-*Rhizobium* symbiosis to combined N and the critical whole plant N concentration for maximum growth. Rooted cuttings were transplanted into 15 kg of Delhi sandy loam soil in crocery pots. KNO_3 was mixed into the soil at rates equivalent to 0, 40, 80, 160, or 320 mg N kg^{-1} soil. Ten replicates were arranged in a randomized complete block design on benches in the greenhouse. Cuttings were transplanted on 6-5-80 and harvested on 11-23-81, 535 days later. Tops and roots were dried, weighed, ground, and analyzed for N using Kjeldahl techniques. The percentage of plant N fixed during the growing season was estimated using ^{15}N techniques; the KNO_3 was enriched by 0.048 atom percent excess (130 $\delta^{15}N$ units).

Table 4.--Acetylene reduction, H_2 evolution, and yield of nodulated mesquite seedlings. Values in parentheses are standard errors of the mean. Eleven plants were inoculated per strain and plants tested and harvested 120 days post inoculation.

Strain	Nodulated plants	H_2 Evolved	C_2H_2 Reduced	Relative Efficiency[1]	Nodule Mass	Total Plant Yield
		--nM $plant^{-1}$ hr^{-1}--		%	---mg dry wt---	
WR1001	11	1423 (388)	5426 (1233)	74 (3)	136 (18)	3105 (633)
L5	11	--	--	--	30 (6)	534 (54)
L9	11	277 (69)	4512 (886)	94 (2)	140 (24)	3490 (696)
176A32	5	57 (26)	4249 (923)	99 (1)	121 (35)	4378 (1107)
Control (<1mM N)	1					360 (37)
Control (+8mM N)	1					17310 (1361)

[1]Relative Efficiency = [1 - (H_2 evolved)/(C_2H_2 reduced)]·100

Yield increased with the addition of 40 mg N kg^{-1} soil, then remained unchanged up to 160 mg N kg^{-1} soil, and decreased as N increased from 160 to 320 mg N kg^{-1} soil (fig. 1). The concentration of N in the tissue (shoot + root) increased with increasing N applied, from 14 g kg^{-1} to 21 g kg^{-1}. The apparent increase in N concentration and uptake between 40 and 80 mg N kg^{-1} soil was not reflected in greater growth, suggesting that a whole-plant N concentration of 16 g N kg^{-1} plant is sufficient for maximum growth. The 40% yield increase observed with the first increment of N addition suggests that, for this system, N_2-fixation was limiting growth either by supplying insufficient N or by utilizing too much carbohydrate. Apparent fixed N (mg/plant), calculated using the $\delta^{15}N$ technique, decreased by about 20% with the first increment of added N, then remained about constant to 160 mg N kg^{-1} soil, finally dropping to half of the unfertilized soil estimate at 320 mg N kg^{-1} soil.

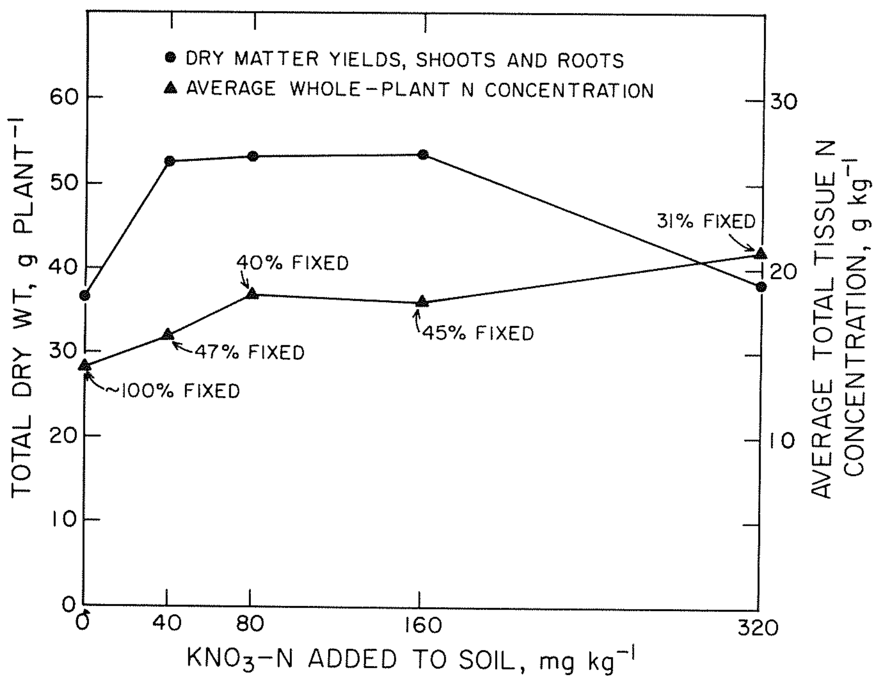

Figure 1.--Mesquite yield, N content, and N_2-fixation as a function of added combined N.

The results suggest that mesquite growth benefits from the application of fertilizer N, but fixation is not greatly inhibited (< 20% inhibition) until soil N exceeds 160 mg N kg^{-1} soil. Even at 320 mg N kg^{-1} soil nearly a third of the plant N was derived from N_2-fixation.

CHILEAN PLANTATIONS

Prosopis tamarugo (commonly called "tamarugo") is native to the northern Chile Atacama Desert (precipitation, 5 mm yr^{-1}). In most areas the trees survive solely on groundwater derived from the Andes for their transpiration requirements (Mooney et al. 1980). Tamarugo and a Peruvian Prosopis have been planted here for 100 years, and have been exploited for building materials, charcoal (domestic and commercial) and forage. Since the demise of nitrate mining in this area, the Chilean government has increased plantings in the region, primarily to provide forage for livestock (Kirby 1972). Goats perform best on the diet of tamarugo pods and leaves, while cattle show the least promise for exploitation of this material and sheep are intermediate.

A survey of plant heights in the 22,000 hectares of plantation revealed that there were substantial differences in annual growth rates of trees, presumably due to soil factors. Depth to groundwater, groundwater salinity, and elemental deficiencies or toxicities were all suggested as potential yield-determining factors. There appeared to be a relationship between annual increase in height and the concentration of P in the tissue; usually trees with concentrations above 0.12% had fairly high productivity (fig. 2). There was a pronounced relationship between [N] and [P] in tissue; it is possible that low P may have been limiting rates of N_2-fixation (fig. 3). Many nodules, both active and inactive, were found on the surface roots of these trees, so the potential for N_2-fixation appeared to be good. Plant [P] was inversely related to plant [Na] (fig. 4), but cause and effect relationships cannot be inferred from this plot alone. In summary, it appears that low soil P may limit rates of growth and N_2-fixation, but further research must be done to define this relationship.

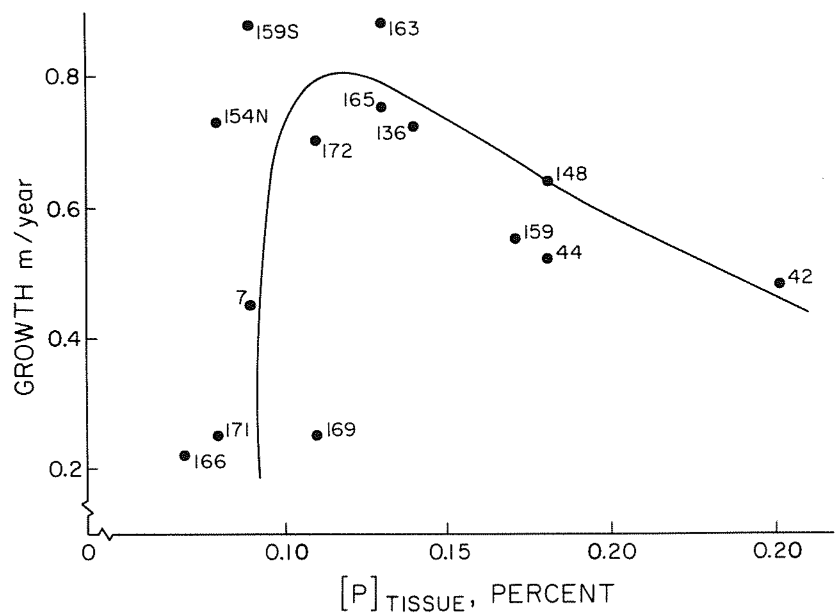

Figure 2.--Growth of Chilean P. tamarugo stands versus foliar [P].

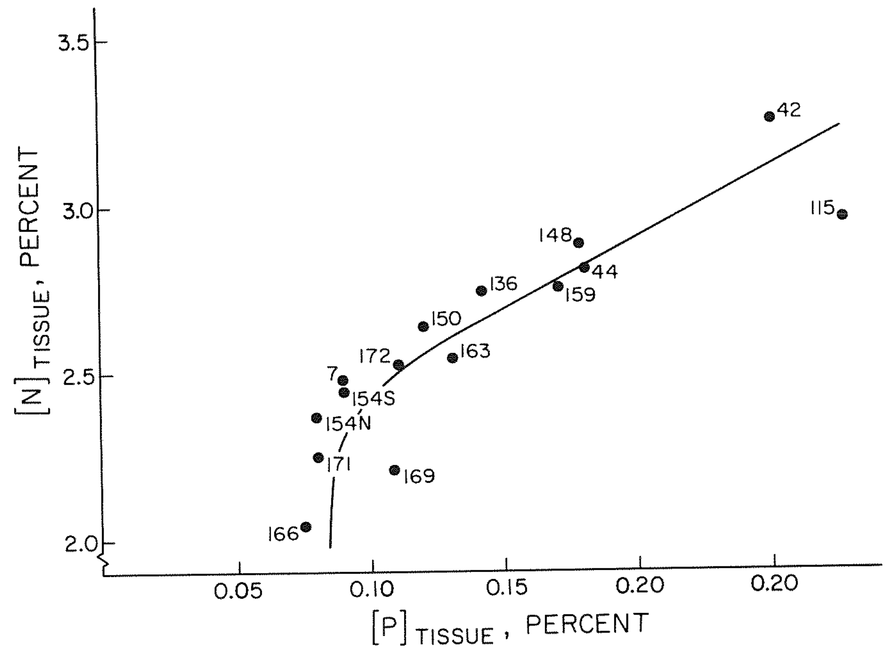

Figure 3.--Foliar [N] versus [P] for Chilean _P_. _tamarugo_ stands.

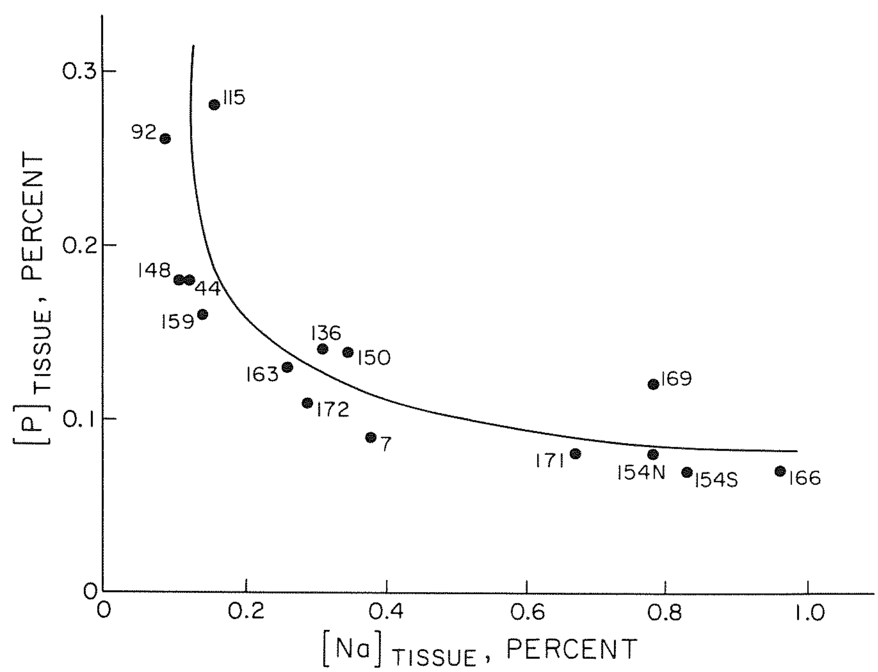

Figure 4.--Foliar [P] versus [Na] for Chilean _P_. _tamarugo_ stands.

MANAGEMENT CONSIDERATIONS

At this stage in the study of N_2-fixation by *Prosopis* species, the following tentative statements or recommendations may be made:

1. Nitrogen fixation by *Prosopis* is widespread and can account for substantial N inputs into mesquite dominated ecosystems. Relative rates of N_2-fixation can be semi-quantitatively measured using the ^{15}N natural abundance technique.
2. Relatively high productivity may occur in native mesquite stands; part of this productivity is due to the plant's ability to fix N.
3. Although numerous rhizobial strains can infect mesquite, these strains vary greatly in their effectiveness, both in terms of increasing growth and in supplying N to the plant. Where mesquite is outplanted into soil in which suitable indigenous rhizobia may not exist, seedlings and soil should be inoculated with cultures of rhizobia which are effective on mesquite.
4. Low availability of phosphorus may limit both productivity and N_2-fixation by mesquite in the field. Plants with leaf tissue concentrations less than 1.2 g kg^{-1} (0.12%) may be P-deficient. Soils from the rooting zone of the trees should be sampled and $NaHCO_3$-extractable P determined to allow P fertilization of deficient sites prior to planting. Critical levels of soil P are not known, but should be determined through research. Any fertilizer P applied must be placed in a depth zone of active roots, within the canopy.
5. The mesquite-*Rhizobium* association can continue functioning effectively even at rather high levels of soil N (160 mg N kg^{-1} soil), but a yield benefit was only noted up to 40 mg N kg^{-1} soil. A true optimum rate probably lies below 40 mg N kg^{-1} soil. Fertilization of the trees with moderate amounts of N may be required for maximum growth rates, but no soil or fertilizer N is required to maintain fairly high rates of plant growth.
6. Much research lies ahead, both to apply and adapt currently known recommendations to extensive plantings in the field, and to learn more about nutrient requirements and N_2-fixation. Various strains of rhizobia should be evaluated in the field to determine which are best suited to surviving and fixing N at high rates. The interaction between mycorrhizal fungi and N_2-fixation requires study as well.

LITERATURE CITED

Allen, O. N., and E. K. Allen. 1981. The leguminosae: A source book of characteristics, uses, and nodulation. 812 p. Univ. of Wisconsin Press, Madison.

Amarger, N. A., A. Mariotti, F. Mariotti, J. C. Durr, C. Bourguignon, and B. Lagacherie. 1979. Estimate of symbiotically fixed nitrogen in field grown soybeans using variations in ^{15}N natural abundance. Plant and Soil 52:269-280.

Bailey, A. W. 1976. Nitrogen fixation in honey mesquite seedlings. J. Range Man. 29:479.

Felker, P. 1979. Mesquite: an all purpose leguminous arid land tree. In G. A. Ritchie (ed.). New Agricultural Crops. AAAS, Westview Press, Boulder, Colorado.

Felker, P., and P. R. Clark. 1980. Nitrogen fixation (acetylene reduction) and cross inoculation in 12 Prosopis (mesquite) species. Plant and Soil 57:177-186.

Fisher, C. E., G. O. Hoffman, and C. J. Scifres. 1973. The mesquite problem. In Mesquite., Texas A&M University Agric. Exp. Stn. Res. Monogr. 1:5-9.

Hua, S. S. T. 1981. Response to salinity in mesquite-Rhizobium symbiosis. p. 467. In A. H. Gibson and W. E. Newton (eds.), Current perspectives in nitrogen fixation. Australian Acad. Sci., Canberra.

Kirby, J. M. 1972. Chile's tamarugo project. World Crops 24:296-298.

Klemmedson, J. O., and R. C. Barth. 1975. Distributional balance of biomass and nutrients in desert shrub ecosystems. U.S./I.B.P. Desert Biome Res. Memor. 75-5, Vol. 3, Logan, Utah.

Knowles, R. 1980. Nitrogen fixation in natural plant communities and soils. p. 557-582, In F. J. Bergersen (ed.), Methods for evaluating biological nitrogen fixation. John Wiley & Sons Ltd.

Kohl, D. H., and G. Shearer. 1980. Isotopic fractionation associated with symbiotic N_2-fixation and uptake of NO_3^- by plants. Plant Physiol. 66:51-56.

Kohl, D. H., G. Shearer, and J. E. Harper. 1980. Estimates of N_2-fixation based on differences in the natural abundance of ^{15}N in nodulating and nonnodulating isolines of soybeans. Plant Physiol. 66:61-65.

Mariotti, A., F. Mariotti, N. Amarger, G. Pizelle, J. M. Ngambi, M. L. Champigny, and A. Moyse. 1980. Fractionnements isotopiques de l'azote lors des processus d'adsorption des nitrates et de fixation de l'azote atmospherique par les plantes. Physiol. Veg. 18:163-181.

Mooney, H. A., S. L. Gulmon, P. W. Rundel, and J. Ehleringer. 1980. Further observations on the water relations of Prosopis tamarugo of the northern Atacama Desert. Oecologia (Berl.) 44:177-180.

NAS. 1975. Underexploited tropical plants with promising economic value. 189 p. Nat. Acad. Sci., Washington, D.C.

NAS. 1979. Tropical legumes: resources for the future. 331 p. Nat. Acad. Sci., Washington, D.C.

Parker, K. W., and S. G. Martin. 1952. The mesquite problem on southern Arizona range. USDA Circular 968, 70 p.

Pate, J. S. 1977. Functional biology of dinitrogen fixation by legumes. p. 473-517. In A treatise on dinitrogen fixation section III: biology. R. W. F. Hardy and W. S. Silver (eds.) John Wiley & Sons Inc., New York.

Pepper, I. L., T. C. Tucker, M. S. Miller, and K. L. Josephson. 1980. Isolation of nitrogen fixing organisms from Sonoran Desert legumes. Agron. Abst p. 158.

Rundel, P. W., E. T. Nilsen, M. R. Sharifi, R. A. Virginia, W. M. Jarrell, D. H. Kohl, and G. B. Shearer. 1982. Seasonal dynamics of nitrogen cycling for a Prosopis woodland in the Sonoran Desert. Plant and Soil Suppl. In Press.

Schubert, K. R., and H. J. Evans. 1976. Hydrogen evolution: A major factor affecting the efficiency of nitrogen fixation in nodulated symbionts. Proc. Nat. Acad. Sci. USA 73:1207-1211.

Sharifi, M. R., E. T. Nilsen, and P. W. Rundel. 1982. Biomass and net primary production of Prosopis glandulosa (Fabaceae) in the Sonoran Desert of California. Amer. J. Bot. 69:760-767.

Shearer, G., and D. H. Kohl. 1978. ^{15}N abundance in N-fixing and non-N-fixing plants. p. 605-622. In A. Frigerio (ed.), Recent developments in mass spectrometry in biochemistry and medicine Vol 1., Plenum Press, New York.

Shearer, G., D. H. Kohl, and S. H. Chien. 1978. The nitrogen-15 abundance in a wide variety of soils. Soil Sci. Soc. Am. J. 42:899-902.

Shearer, G., D. H. Kohl, and J. E. Harper. 1980. Distribution of ^{15}N among plant parts of nodulating and nonnodulating isolines of soybeans. Plant Physiol. 66:57-60.

Shearer, G., D. H. Kohl, R. A. Virginia, B. A. Bryan, J. L. Skeeters, E. T. Nilsen, M. R. Sharifi, and P. W. Rundel. In Press. Estimates of N_2-fixation from variation in the natural abundance of ^{15}N in Sonoran Desert ecosystems. Oecologia (Berl.).

Szarek, S. R. 1979. Primary production in four north American deserts: Indicies of efficiency. J. Arid Environ. 2:187-209.

Turner, G. L., and A. H. Gibson. 1980. Measurement of nitrogen fixation by indirect means. p 111-138. In F. J. Bergersen (ed.), Methods for evaluating biological nitrogen fixation. John Wiley & Sons Ltd.

Virginia, R. A., and C. C. Delwiche. 1982. Natural ^{15}N abundance of presumed N_2-fixing and non-N_2-fixing plants from selected ecosystems. Oecologia (Berl.). In Press.

Virginia, R. A., W. M. Jarrell, and E. Franco-Vizcaino. 1982. Direct measurement of denitrification in a Prosopis (mesquite) dominated Sonoran Desert ecosystem. Oecologia (Berl.) 53:120-122.

Virginia, R. A., E. T. Nilsen, M. R. Sharifi, W. M. Jarrell, and P. W. Rundel. 1982. Nitrogen cycling in a California Sonoran Desert mesquite (Prosopis glandulosa: Fabaceae) woodland. Bull. Ecol. Soc. Am. 63:94-95.

DRYING, SEPARATION AND PRIMARY PROCESSING

OF COMBINED MESQUITE CHIPS[1,3]

Willie L. Ulich[2]

Abstract - Rolling Plains whole-tree honey mesquite samples were found to average 47.2% moisture during the late summer months. Combined harvested mesquite chips dry rapidly in windrows, large wire baskets, and loose stacked ricks. Six foot ricks dried below 20% moisture within a 21 day ambient air drying period. Rain on the material caused mildew, however, top covered ricks provided adequate quality control. Contrary to expectations, interior loose rick temperatures remained 10°C below maximum ambient air temperatures.

Whole-tree mesquite chips, combine harvested under various conditions, show an average of about 1/3 leaves, beans, grass, and small wood particles; 1/3 shredded bark and barked wood; and 1/3 debarked wood. Of three types of mechanical separators constructed, an angled revolving wire mesh cylinder type proved the more economical and provided desirable separation. The first separation placed an average of 28.75% of the total weight in the leaf, bean, and wood splinter sorter container.

Investigations in the primary processing, packaging for transport, size reduction, and forming are currently in progress. These processes are primarily dependent upon the ultimate use. Although large wire baskets and dry baling have been used, the loose rick with self-loading rick trucks appear the more economical method of drying and transporting. Total and separated material have been reduced in size, ranging from meal to 1 inch chips, by the use of hammer mills. Fire logs, wafers, pellets, graded chips, fiber boards, particle boards, brickets, and leaf meal have been produced from the combined mesquite chips on a limited scale.

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[1]Presented at the Mesquite Utilization Symposium, Texas Tech University, Lubbock, Texas, Oct. 29 & 30, 1982.

[2]Willie L. Ulich is Professor of Agricultural Engineering, Texas Tech University, Lubbock, Texas

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INTRODUCTION AND CHARACTERISTICS OF COMBINED MESQUITE CHIPS

Basically Mesquite trees growing in a given area are characterized by variable size, crooked thorny trunks and limbs growing at various angles with the soil surface. Characteristically the trees have a dark reddish brown heart section covered by light colored new growth material. The leaf area is rather small compared to other leaf trees. The trees produce light brown flattened oval shaped beans in pods 4 to 6 inches in length. The mesquite wood is above average wood density. The tonage per acre varies from scattered to as much as 20 greens tons per acre. In earlier investigations under this project it was determined that there were some 13.3 million acres of mesquite on the Texas Rolling Plains. Of this acreage, 3.7 million acres of shallow land was classified as light infestation, 5.1 million acres of deep upland as medium infestation, and 4.5 million acres of bottom land as heavy infestation. Field checks indicate the green weight biomass to be 1.83/tons/acre for light infestations, 8.6/tons/acre for medium infestations, and 16.1/tons/acre for heavy infestations. Of the estimated 124 million green tons on the Rolling Plains, it is estimated that 117 million green tons, on 9.6 million acres, would be suitable for utilization.

The primary objective of the study, herein reported, was to develop an economical system of quality control of mesquite from harvesting to initial or primary processing. This paper is thus confined to the drying, separation and other primary processing of whole-tree mesquite chips harvested by a once-over mesquite combine harvester. A preceding paper dealt with this method of harvesting. The current harvesting cost was estimated to be $7.46 per green ton dumped in a loose rick at a central site of the harvesting area. The green material contained approximately 47.2% moisture, on a wet basis, during the growing season. The harvested material varied in size from fines to a maximum size of 0.75 inches in diameter and 7 inches in length. Approximately 86% of the material was 4 inches or less in length. The bulk density of the green cut material when dumped into rick shaped piles was determined to average 15.18 lbs. per cubic foot.

Depending upon the area being harvested and the season of the year, the percent of small particles, leaves, beans, and grass varied from a low of 31% to a high of 39% by weight of the total material. Shredded bark varied from 6 to 8%, chips and stems with bark 24 to 27% and debarked material 31 to 36%. The average being about one third, by weight, as smaller material, one third bark and barked chips, and one third debarked chips.

DRYING OF COMBINED MESQUITE CHIPS

It was assumed, due to high moisture of the field cut mesquite, that field drying would be the most economical method as it would utilize ambient air and greatly reduce transportation costs. Field drying in windrows, baskets, and loose piled ricks were investigated. Although, windrow harvesting would reduce the cost of initial harvesting and permits faster drying, there are some inherent problems associated with this method. These problems include satisfactory equipment to pick up the windrow; additional equipment costs; high pick-up loss of leaf and small particles; and quality losses from rains, windstorms, and livestock. Baling of the material also had some inherent problems. Compaction before drying causes heating of material and loss of quality. Material field dried to below 20% moisture and baled, to the larger rectangular hay bale size, weighed 110 lbs./bale and experienced no notable quality deteriation in a limited investigation.

A 200 cu. ft. covered angle-iron wire basket was filled with combined mesquite chips and dried in the field with no observed quality loss. The basket idea encorporated a convenient system of loading, transporting and unloading. The number of baskets which would be required for basket drying, however, did not prove to be an economical system. Dr. Milton Smith's 1981 report on the "Economic Analysis of Mesquite Harvesting and Utilization", shows the basket method to be the more costly of the systems investigated. In all cases, when the material was in a pile and did not have a top cover, a rain of .25 inches or more caused the material to mildew. Rain will also cause the exposed chip material to absorb moisture and turn a motley black color. Although the loss of quality was not determined, the loss would undoubtly effect certain uses of the material, such as feed and partical board.

The most economical method of drying was simply dumping the fresh cut material from the combine basket into non-packed ricks. The ricks were approximately 6 ft. in height with a 10 ft. base. The angle of repose of the green material was determined to be approximately 47 degrees. Although there is some shrinkage in volume when the stack is dried, if the stack is disturbed and restacked in a loose condition, the volume is again increased. In other words, if the stacks are disturbed in the loading process, the volumetric space required for a transportation vehicle would need to be about equivalent to the green mass volume. Disturbed or loose 20% moisture total material is in the range of 9-11 lbs. per cu. ft.

The climatic conditions will, of course, determine the rate of drying. Records were kept on a rick of material at Post, Texas during August and September with the following results. During the first 24 hours the wet moisture content was reduced from 47.2% to 42.9%. After the first seven days of field drying the moisture was found to be 28.6%. By the end of two weeks the moisture was 23.1%. After field drying three weeks the moisture was reduced to 16.9% and at the end of four weeks the moisture reached to a low of 12.4%. In one case a 3 inch rain was experienced on an uncovered rick having an approximate 17% moisture content. By the following day the moisture had climbed back to an average of 38%.

Temperatures within ricks of total combine mesquite, during the field drying process were found to be opposite from normal expectancy of stacking green material. Ambient air temperatures were related to the average of interior temperatures taken at one foot intervals from a point one foot from the surface to the center of the rick. During a 21 day period the maximum ambient air temperature averaged 32.7°C and the maximum interior temperature averaged 22.8°C. In addition to the interior being protected from direct sun rays, the ricks and the moisture evaporation process further reduces the interior temperatures.

Due to the problems encountered from rain, several means of covering the ricks were investigated. The lowest material cost method was the use of plastic sheeting, however, the chip thorns, disturbance by animals, and high winds caused the plastic sheeting to tear and fail its purpose. Heavier reinforced similar tenting material covering the top two-thirds of the rick provided adequate protection and quality control. When one-third of the sides of the ricks were open the rate of drying was reduced approximately 8%. The use of 8 ft. by 8 ft. frames covered with corrugated fiberglas semi-transparent roofing material was also investigated. Ricks were covered with panels positioned flat across the top of the ricks and also in a leaning or "A-frame" position with ends open in both cases. Both methods were satisfactory in reducing the rain damage, with the "A-frame" system being slightly superior in total quality control. Neither of the rigid frame configerations caused any appreciable reduction in the drying rate compared to uncovered ricks.

Although further investigations are needed for a final conclusion, the combined mesquite chips can be satisfactorily field dried. To conserve quality some type of cover appears highly desirable. The need for a cover, however, apparently is to a certain extent dependent on the final utilization of the product.

SEPARATION OF MESQUITE FIELD DRIED CHIPS

One of the inherent problems of whole-tree harvesting is that of having a mixture of materials in respect to size, shape, and qualitative values. Some proclaim segregation is the key to whole-tree utilization .... (Erickson-1970). In regard to combined mesquite chips, the need and extent of segregation is dependent upon planned utilization. Now known and new uses may determine the need of separation of materials in order to maximize the value of mesquite chips. Analysis of mesquite leaves and beans indicate a relatively higher valued product from that of total combined mesquite chips. As an example, by separation it may be possible to produce a higher value feed and at the same time provide a higher quality wood chip for producing building products. Our investigations were thus to separate leaves, beans, grass and small stems from the total mass. This material was earlier determined to be about one-third of the total material harvested.

Three types of experimental separators were designed, constructed, and performance tested. They consisted of an aspirator separator, a vibrating screen separator, and a revolving cylinder separator. After construction, replication tests were performed using each device. The data obtained were evaluated on the basis of separation performance, initial cost, operating cost, and rate of separation. The aspirator separator consisted principally of a vertical cylinder into which the total material was augered into near the top. An upward airstream moved the lighter material into a cyclone collector while the heavier material dropped by gravity into a hopper at the bottom of the cylinder. The separation was performed based upon the density, size and surface characteristics of the materials. This system can be easily adjusted simply by adjusting the velocity of the air stream and could provide for varying moisture content of the total material. Although this system has merit a large percentage of the bark was deposited with the leaf material. The cost and power requirement was also relatively higher than the other methods used and was thus rated lower than such methods.

The forestry chip industry has been relatively successful in utilizing an angled vibrating screen, however, an attendant is usually needed to sweep chips entangled in the screen. Due to the characteristics of mesquite chips, a modified version of the vibrating screen was constructed. This segregation device permitted varying screen size, angle of the screen, and stroke length. A .75 inch screen, at a 22-25° angle, and a 2.25 inch stroke gave the best results. At this setting, 28.75% of the material was separated into the fine category. A major problem, however, was material getting clogged in the screen. A modification of having the material drop on a solid vibrating surface improved the performance, however, did not eleviate the problem. Although it is possible of using an automatic screen cleaning device the final cost is estimated to exceed a third method investigated.

Although the revolving screen separator did not initially provide the most effective separation, it was desirable from an energy requirement, size-capacity, and minimum cost standpoint. This device consists of a wire covered revolving cylinder covered with a wire screen and set with a tilt or angle. This device was self cleaning. After several modifications it proved to be the most desirable of the types investigated. After some 30 tests the current model consists of a skeleton cylinder 24.5 inches in diameter, 75 inches long, covered with a .25 inch hole screen, set at a 9.6° angle and driven at 40 to 45 rpm. Repetitive separation at an average of 24.75% into the leafy material category averaged 1813 lbs. per hour when hand fed. This device was driven with a .5 h.p. motor and can safely handle a ton per hour if mechanically fed by a mechanical conveyor. Increased diameter and length would undoubedly increase the capacity.

To date, we have not investigated the separation of bean pods from the leafy material nor the separation of bark from the base stock, both of which may be highly desirable or required for certain uses. Although the pods are reduced in size, little shelling was noted in the harvesting process. Separation of the pods and bark from the wood chips apparently will not be an easy task. The USDA Forest Service is currently conducting bark separation tests based upon: (1) air flotation, (2) compression and (3) liquid-medium principles (Erickson, 1971). Separation requirements will in the end depend upon ultimate economic utilization.

SIZE REDUCTION AND FORMING OF MESQUITE STOCKS

The primary processing of mesquite chips is herein limited to providing a uniform basic stock material which can be utilized by secondary processors for manufacture into the ultimate consumable product. Basically, in this area we are currently concerned with size reduction and/or forming of the material to provide such a stock material. To date my investigations have been quite limited and again depends upon final utilization. Other speakers at this symposium have or will discuss possibilities and costs for final utilization.

Although the harvester could be altered to change the size of the combined mesquite chips, if the demand indicated such needs, this effort is based upon the current product harvested. The material when harvested had a bulk density of 15.18 lbs./cu.ft.; after 4 weeks of field drying - 9.38 lbs/cu.ft. and when finely ground 32.24 lbs./cu.ft. As given earlier, about 28.75%, by weight, can be mechanically separated into the fine category. One large sample of 19% moisture combined mesquite was submitted to Aerospace Research Corporation, Roanoke, Virginia, which under a Department of Energy Contract, performed an analysis. The results, based upon percent of weight were as follows: carbon 53.49%, oxygen 36.33%, hydrogen 6.45%, nitrogen 1.065%, sulfur .086%, chloride 0%, and ash 2.58%. The total heat value was found to be 8504 Btu/lb. which was slightly less than Virginia Pine, about the same as yellow Poplar, and more than that of Sycamore and Red Oak. From this analysis the strochiometric quantity of air required for complete combustion would be 6.81 lbs. of air/lb. of mesquite chips.

Except for use as a boiler fuel, the material will likely require a size reduction. Several investigators are currently working on new burners or improved burners to utilize this size material. The major effort is to reduce the burner size now required for a given heat rating. To date our investigations in size reduction have been limited to the use of a hammer mill. Screens used were .25 inch, .5 inch, and 1 inch. Although the mill used a cyclone collector, some of the fines were expelled into the ambient air. The lower capacity was, of course, when the .25 inch screen was used. The capacity varied from 1600-1800 lbs./hr. and required an estimated 15-20 horsepower. This method was used to reduce material for processing feed as reported by others at the symposium. Undoubtedly a modified hogging machine, which uses grates rather than screens, would be a more economical means and should be investigated. Investigators at the University of California have had success in using a tub grinder to reduce tree prunings. At least one firm is using a ball-mill for reducing similar material. These machines also offer possibilities for grinding mesquite chips.

It is estimated that the properties of mesquite chips are such that they could be substituted in 90% of current wood chip utilization. One of the major problems, however, is the tonnage per acre is considerably less and where long transportation hauls were necessary, mesquite chips may not meet economic competition. As an example, paper could be manufactured from mesquite, and with the exception of slightly higher bleaching costs, could be competitive on a wood to wood comparison. Paper mills, however, are large high investment plants requiring large volumes of pulp material. With an average consumption of 1200 cords/day of a paper plant, the supply of mesquite in an area would be exhausted within a short time. It is estimated that under current conditions mesquite utilization would be economically limited to plants requiring less than a 750 ton daily utilization rate. More recently there has been considerable interest in producing alcohol from woody materials. One report indicates mesquite wood to produce only 28 gallons of 95% alcohol per ton as compared to 49 gallons from a ton of pinewood.

In early times wood provided 90% of all the fuels used in the United States. Only the discovery of petroleum averted an earlier energy crunch. Due to the current high prices of petroleum, we are again seriously considering wood as an energy source. A 1977 MITRE report gives fifteen alternative conversion routes for producing energy related products from wood biomass. The Department of Energy and other agencies are currently funding a number of research projects, in this area of work, to produce new technology. Many companies are also seeking and purchasing wood scraps as supplementary fuel stock. One plant executive said, "At our present fuel costs we can save money by substituting wood at $30.00/ton." Several firms are making studies on the use of wood scraps and chips as an energy source for electrical generating plants.

Principally due to its high density the amount of energy per volume in mesquite is rather high and, therefore, offers a good possibility as a competitive specialized fuel source (Marshall 1947). Harvested mesquite chips could be used for small heating plants such as residences (Riley 1979). Energy pellets made from lumber manufacture are now being marketed. A TAIGA international report on burn-test of wood also indicates that mesquite chips would be suitable for pressed log (Cambell 1980). A Swedish generator gas report clearly indicates that mesquite chips could be utilized to propel moving type vehicles such as autos and tractors (U.S. Department of Commerce 1979).

At least one manufacturer is pelletizing tree bark into a high density pellet under a trade name of "Energy Pellets." Mesquite chips, due to high density stock, could be highly competitive in such a market. There has been some regional interest in producing fireplace logs from combined mesquite chips. A brief analysis indicates a standard 11.5 inch by 3.5 inch four to five lb. fireplace log could be produced for less than $0.28 when using the combine harvesting method described earlier today. Charcoal, brickets, wafers and mesquite powdered fuel offer other possiblities.

It was found that combined mesquite chips can be utilized in the manufacture of both particle board and fiber board for the building construction industry. A section of particle board was produced in the laboratory from reduced total mesquite combine chips. Except for the chlorophyll causing a darker color this board had similar characteristics to that of commercial manufacture. Separation of the leaves and bark would undoubtedly have improved appearance, sanding qualities and reduced the glue ratio required. If mesquite is used as stock for either particle board, flake board, or fiber board the method of final size reduction should be performed by some type of flaker which provides for longer fiber length cuts and thus provides for stronger boards. This would be mandatory for fiber board production. Particle or flake board also requires a low moisture and uniform size chip. When uneven size chips are used and the board becomes wet, the larger particles swell more and cause bowing or an uneven surface. The preliminary investiations, to date, indicate quality building products can be manufactured from mesquite chips.

SUMMARY AND CONCLUSIONS

Investigations indicate field drying of mesquite chips can be economically accomplished for most ultimate uses. Some type of top cover of field ricks is required for quality control. A three week field drying period produced chips below 20% moisture under favorable climate conditions. A four week drying period reduced the moisture to near 12% moisture.

Separation appears desirable for maximizing the value of mesquite chips. An angled wire covered revolving cylinder proved to be an economical method of separating leaves, beans, and small particle separation. Although investigations are needed to determine the affect of increased cylinder size on machine capacity, this method proved to be more desirable of the methods investigated to date.

The use of hammer mill to reduce the size of combine harvested mesquite chips proved to be a satisfactory method. Further investigations using modified hoggers and tub grinders are needed for a final recommendation. The final product utilization is a paramount factor, in drying, separation, and grinding of mesquite chips. Where possible elimination of any or all of these operations will reduce the utilization tonnage cost. Further economic studies are needed to give a final processing system recommendation.

MAJOR REFERENCES (Con't)

Marion, P. T. Fisher, C. E. and Robinson, E. D. 1957. Ground Mesquite Wood as a Roughage in Rations for Yearling Steers. Texas Agr. Exp. Sta. Progress Report.

Marshall, E. C. 1947. Mesquite Utilization in Texas. The Chemourgic Digest, Vol VI. No. 5.

Parker, H. W., Albin, R. L., Vernor, T. E. and Fahle, D. W. 1977. Thermochemical Modification of Mesquite for Ruminant Rations. Second Pacific Chemical Engineering Congress, Denver. Colorado.

Parker, H. W. and Whetstone, G. A. 1974. Fuels and Petrochemical Feed Stocks from Agricultural Waste. Chemical Engineering Progress Symposium, Series #142, Vol. 70.

Riley, J. G. and Smyth, D. A. 1979. Small-Scale Space Hearing with Wood-Waste. Brush and Logging Residue Fuels, American Society of Agricultural Engineering, Paper No. 79-1608.

Schoffelmayor, V. H. 1945. Mesquite Trees of Texas Produce an Important Gum. Texas Chemurgic News, 1945.

Smedley, J. 1966. Mesquite Floors for Beauty and Durability. Texas Forestry News, 1966.

Soltes, E. J. 1977. Expanding Energy Role of Wood. Texas Energy and Mineral Resources. Vol. 3, No. 7. Texas A&M University, May 1977.

Stayton, L. L., Smith, W. A. and Hoffman, G. O. 1971. Saltcedar and Mesquite for Wood Pulp, Board Proudcts, Animal Nutrition and Soil Amendment - a Proposal for Improving Range Environment. Texas Ag. Ext. Serv. Mimeo.

Sturos, J. A. and Dixon, R. E. 1977. Fiber, Fuel, and Food from Whole-Tree Chips. National American Society of Agricultural Engineers Paper No. 77-1578.

Thayer, D. W. 1975. Optimization of a Submerged Culture Process for Production of a Complete Cattle Feed from Mesquite Wood. Protein from Cellulose Abstracts, Texas Tech University, Vol. 16, 465-474.

Ulich, W. L. and Burzlaff, D. F. 1978. Field Quality Control of harvested Mesquite Chips. Brush and Weed Control Highlights. Texas Tech University, Vol. 9.

Ulich, W. L. and Burzlaff, D. F. 1978. Harvesting and Initial Processing of Brush as an Energy Source. Southwest American Society of Agricultural Engineers Paper No. 78-08.

MAJOR REFERENCES

Buckman, R. E. 1978. Structural Flakeboard Residues. Forest Service - USDA. General Technical Report WO-5.

Cambell, D. G. 1980. Facts in Support of Pressed Wood Fuel. TAIGA International Burn-Test Comparisons. TAIGA Bulletin.

Cambell, D. G. 1979. Production of Mod-Logs. TransArtic Air Ltd. Correspondence and Exhibits. July 1979.

Cedergreen, J. H. 1971. Industry Outlook in Mechanization. Proceedings of Conference on Biological and Economic Considerations in Mechanized Timber Harvesting. Univ. of Minn. Exp. Sta. Miscellaneous Report #116.

Durso, D. F., Allen, T. J. and B. J. Ragsdale. 1973. Possibilities for Commercial Utilization of Mesquite. Mesquite Research Monograph 1. November 1973. Texas A&M University.

Erickson, J. R. 1971. Bark-Chip Segregation; A key to Whole-Tree Utilization. Forest Products Journal 21 (9) 111-113.

Forbes, R. H. 1975. The Mesquite Tree: Its Products and Uses. Ariz. Agr. Exp. Sta. Bulletin No. 31.

Gaul, D. F. and Bartsch, R. A. 1979. Survey of Literature Pertaining to Extraction of Chemicals From Mesquite. A Dept. of Chem. Report, Texas Tech University.

Goldstein, I. S. and Villarreal, Anita. 1971. Chemical Composition and Accessibility to Cellulose of Mesquite Wood. Wood Science Journal, 1971.

Hamrick, T. J. 1978. Development of Wood as an Alternative Fuel for Large Power Generating Systems. U.S. Dept. of Energy publication, ORO-5682-8.

Hassan, A. E. and Reeves, R. H. 1980. Compaction of Wood Chips - Physical and Pulping Characteristics. American Society of Agricultural Engineers Transactions, pages 270-274.

Katzen, Raphael. 1977. Methanol from Wood Biomass. Proceedings of Conf. on Chem. Feedstock Alternatives. AICE NSF/RA-780187.

King, G. W. 1980. Equipment for Wood Chip Quality Control. Williams Pat. Crush and Pulv. Co. Bulletin 766.

Laundrie, J. F. 1958. Pulping of Mesquite, Manzanita and Snowbrush. Forest Prod. Lab. Mimeo 2138, Madison, Wisconsin.

MAJOR REFERENCES (Con't)

Ulich, W. L. 1980. Mesquite Brush Utilization and Harvesting Equipment. Paper presented at the Southwest American Society of Agricultural Engineers Conference, San Angelo, Texas, October 30, 1980.

Ulich, W. L. 1979. Development of a Mesquite Combine. Technology, an engr. student publication, Texas Tech University.

U.S. Dept. of Commerce. 1979. Gas, the Swedish Experience from 1939-1945. Solar Energy Research Institute, NTIS Publication, SERI/SP-33-140.

U.S. Forest Service. 1980. Fuel Value Calculations. Calculations prepared by U.S.F.S. S-E area.

ISOLATION OF NON-CARBOHYDRATE, ORGANIC CHEMICALS FROM MESQUITE[1,2]

Richard A. Bartsch,[3] Shou-Jen (Richard) Chen,[4] and J. Scott Pendergrass[4]

Abstract.—The extraction, separation, and identification of non-carbohydrate, organic chemicals from segregated parts of the mesquite plant have been studied. Mesquite heartwood is found to contain significant amounts of extractable, poly-phenolic compounds. A unique flavinol "Mesquitol" has been isolated from mesquite heartwood.

INTRODUCTION

An almost totally unexplored area for mesquite utilization involves the use of mesquite plants as a source of organic chemical feedstocks for industry. Assessment of this potential application is severely hampered by a lack of information concerning the chemical constituents, other than carbohydrates, which may be readily recovered from the mesquite plant. Therefore, a research program was initiated in the Department of Chemistry at Texas Tech University to isolate non-carbohydrate, organic compounds from honey mesquite (*Prosopis juliflora*) and identify them.

Since it possesses the greatest potential for practical recovery of organic compounds from mesquite, attention has been focused exclusively on extraction as a method of separation. The first report of mesquite wood extraction was published in 1922. Ritter and Fleck (1922) performed extractions on mixtures of mesquite sapwood and heartwood. Fifty years later, Goldstein and Villarreal (1972) reported the amounts of extracted materials which would be recovered from air-dry mesquite sapwood and heartwood using several solvents (table 1). Although this data clearly establishes that significant amounts of material may be extracted from mesquite sapwood and heartwood, the chemical compositions of the extracts were not determined.

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[1]Paper presented at the Mesquite Utilization Symposium [Texas Tech University, Lubbock, Texas, October 28-29, 1982].
[2]This research was supported in part by line item funds provided by the Texas Legistature entitled "Research in Mesquite Utilization".
[3]Richard A. Bartsch is Professor of Chemistry, Texas Tech University, Lubbock, Texas.
[4]Graduate students in the Department of Chemistry of Texas Tech University.

Table 1.--Extraction of Honey Mesquite

Extraction Solvent	Extraction Yield, Percent of Air-Dry Sample From Sapwood (%)	From Heartwood (%)
Water	6.0	5.8
Benzene-ethanol	4.4	12.2
Benzene-ethanol-water	10.4	18.0
Aqueous sodium hydroxide (1%) solution	20.5	28.9

In 1979, Gaul and Bartsch[5] surveyed the literature for information on non-carbohydrate, organic compounds which had been separated from mesquite (Prosopis juliflora) and identified. A few references dealing with the isolation of certain compounds or classes of compounds such as tannins, waxes, and flavonoids from specific mesquite plant parts or unspecified mesquite sources were located. However, the data were found to be extremely fragmentary and provide little basis for a judgement on whether or not economically-attractive, non-carbohydrate, organic compounds would be extracted from mesquite.

EXTRACTION STUDIES

Source and Preparation of Mesquite Plant Samples

Except where specified otherwise, all mesquite plants were obtained from the field directly opposite the Texas Tech University School of Medicine in Lubbock. Plants had stump diameters of 2 - 4 inches. Freshly harvested plants were separated into component parts (trunk and large branches, small branches and twigs, and leaves). The trunk and large branch portion was separated into bark, sapwood, and heartwood components by means of a razor knife. These segregated materials were then chipped into thin shavings (approximate size of 1/2 cm. x 1/2 cm. x 1/16 cm.) with a razor knife. In no instance was any effort made to dry the chipped samples before extraction.

Extraction Procedure

Extractions were performed by weighing the segregated, chipped mesquite plant part into a cellulose extraction thimble and then extracting with the desired solvent in a Soxhlet extraction apparatus for 72 hours. In a control experiment for the extraction of chipped mesquite heartwood with diethyl ether, a 24 hour period was found to be insufficient to provide for complete extraction. After the extraction was completed, the solvent was removed in a tared flask under vacuum and the weight of extracted material was determined by difference.

[5] Gaul, D. F., and Bartsch, R. A. 1979. Survey of the Literature Pertaining to Extraction of Organic Compounds from Mesquite. Unpublished report. Mesquite Utilization Program, College of Agriculture, Texas Tech University.

RESULTS AND DISCUSSION

Extraction of Different Mesquite Plant Parts

Samples of segregated and chipped mesquite heartwood, sapwood, bark, and leaves from a single harvesting were extracted with diethyl ether. Yields of extracted material based upon the wet weights of the chipped samples were: heartwood, 4.1%; sapwood, 1.1%, bark, 2.2%; and leaves, 3.0%. Visual examination of the leaf extract (green and waxy material) indicated that considerable amounts of chlorophyll and wax were present. Since this preliminary study revealed the heartwood to be the best source of extractable organic compounds, mesquite heartwood was subjected to a more complete investigation.

Extraction of Mesquite Heartwood

Variation of Extraction Solvent.--To determine the best solvent to use for extracting organic compounds from the reddish-brown mesquite heartwood, samples from two harvestings were extracted with different solvents. Results are recorded in Table 2. A requirement for conducting the extraction on heartwood samples which have only been

Table 2.--Effect of Solvent upon Amount of Material Extracted from Mesquite Heartwood

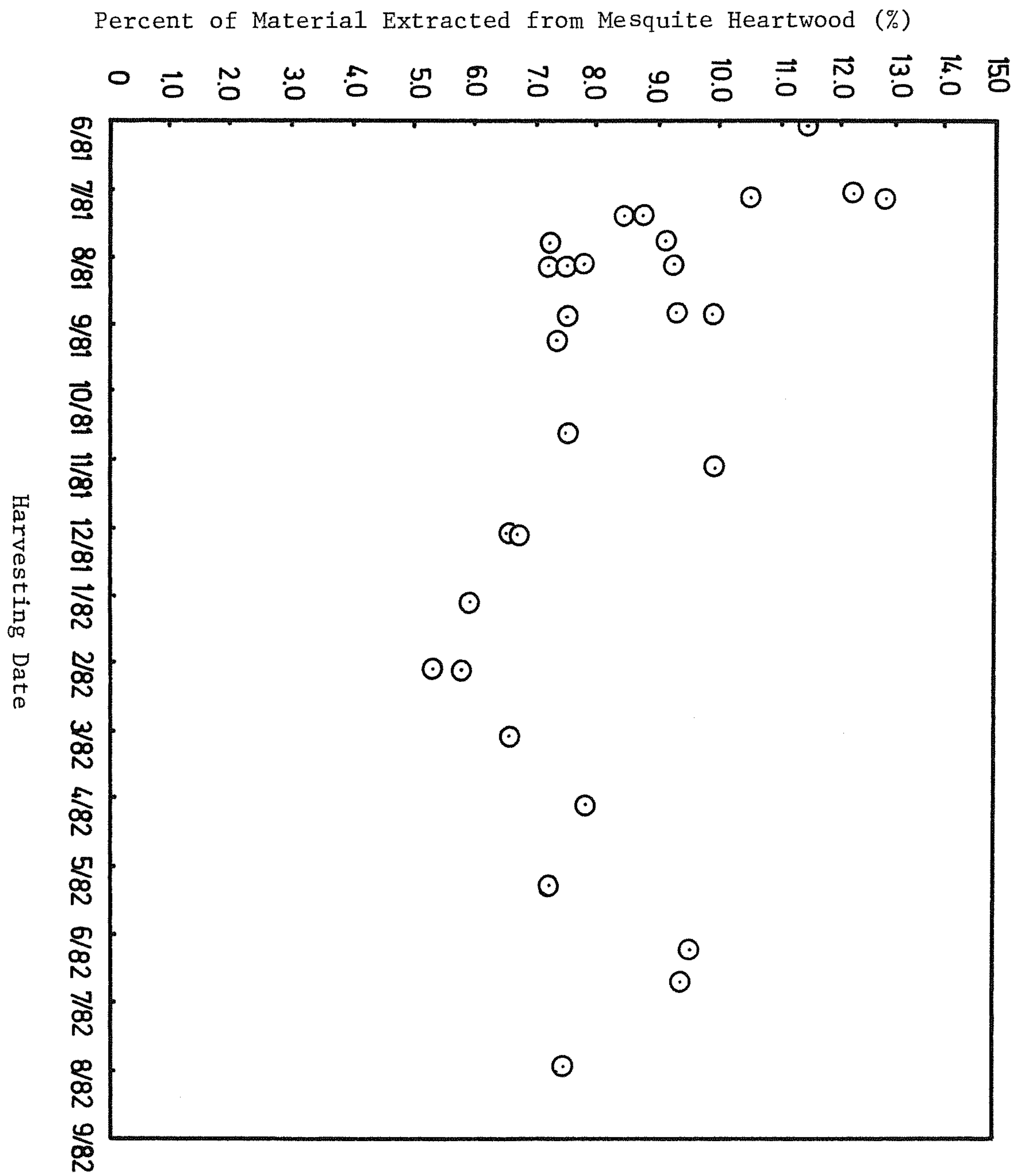
Entry	Mesquite Sample	Extraction Solvent	Yield of Extracted Material, %
1	1	diethyl ether	4.0
2	1	[1]diethyl ether	1.3
3	1	benzene-ethanol(1:2)	10.6
4	2	ethanol	13.1
5	2	benzene-ethanol(1:2)	11.7
6	2	benzene-ethanol(2:1)	11.6
7	2	benzene	2.6

[1]Extraction was performed one month after harvesting.

harvested for a few days is revealed by the data in entries 1 and 2. For entry two, one month had elapsed between harvesting and extraction. Clearly such delay causes an abrupt drop in the yield of extracted material which presumably results from decomposition. Samples 1 and 2 were harvested in mid-March and early August of 1980, respectively, and yields of extracted material show reasonable reproducability for a common extraction solvent (compare entries 3 and 5). The data contained in Table 2 reveals that extraction with ethanol produces the highest yield of extracted material.

Seasonal Variation in Yields of Extracted Material.--Yields of material which was extracted using ethanol(based upon the wet weight of chipped mesquite heartwood)from samples collected at different times of the year are compared in Figure 1. The data reveal that 7 - 13 percent of the mesquite heartwood may be extracted during most of the year.

Figure 1. - Percent of Material Extracted from Mesquite Heartwood at Different Harvesting Dates



However, for the period of December - March, the yields of extracted material are decidedly lower. Failure to reach extraction yields above 10 percent during the summer of 1982 probably results from the extended period of wet weather which increased the water content of the heartwood.

Extraction of Chemically-Defoliated Mesquite.--To determine the effect of chemical-defoliation upon the extractability of mesquite heartwood, samples of treated mesquite were obtained from the farm of Mr. D. E. Sosebee near Anson, Texas. The mesquite had been sprayed on approximately July 1, 1980 with Tordon 225. In early January, a 4 inch diameter trunk from one of the defoliated plants was cut and dug out so that appreciable amounts of material from above-ground and below-ground was available. Samples of chipped heartwood from the above-ground and below-ground portions were prepared and extracted with methanol as before. The above-ground and below-ground mesquite heartwood samples yielded 7.9 percent and 12.5 percent of extracted material, respectively. The somewhat lower percentage obtained from the above-ground mesquite heartwood may result from some decomposition of the extractable organic compounds. However, the magnitude of values for both samples demonstrates that chemical defoliation did not destroy the extractable organic compounds in the heartwood. Instead, these compounds appear to survive in the heartwood of chemically-defoliated, but physically intact, mesquite plants for at least a period of months.

SEPARATION AND IDENTIFICATION OF COMPONENTS IN THE HEARTWOOD EXTRACT

For the separation and identification of components in the material obtained by extraction of mesquite heartwood, the techniques of modern organic chemistry were employed. Separation was accomplished by column chromatography with high pressure liquid chromatography and thin layer chromatography being used to monitor the separation processes. Chemical compositions of the separated components were probed by infrared and proton magnetic resonance spectral examination.

Crude heartwood extracts were separated into polar and non-polar fractions of organic compounds by chromatography on a silica gel column using a solvent of methylene chloride and chloroform to elute the non-polar fraction. The polar fraction which had been retained on the column was subsequently eluted with methanol. After evaporation of the eluting solvent, spectral examination of the non-polar compound fraction showed it to be composed of waxes. Evaporation of the eluting methanol yielded the polar organic compounds as the major component with 55 - 95 percent of the crude extract weight being recovered in this fraction (Figure 2). Spectral examination of the polar compound fraction indicated the presence of poly-phenolic compounds and the absence of carbohydrates. A high pressure liquid chromatogram (Figure 3) revealed that the polar fraction was still a complex mixture of compounds. Details for this chromatographic analysis and subsequent separations by column chromatography may be obtained from the thesis

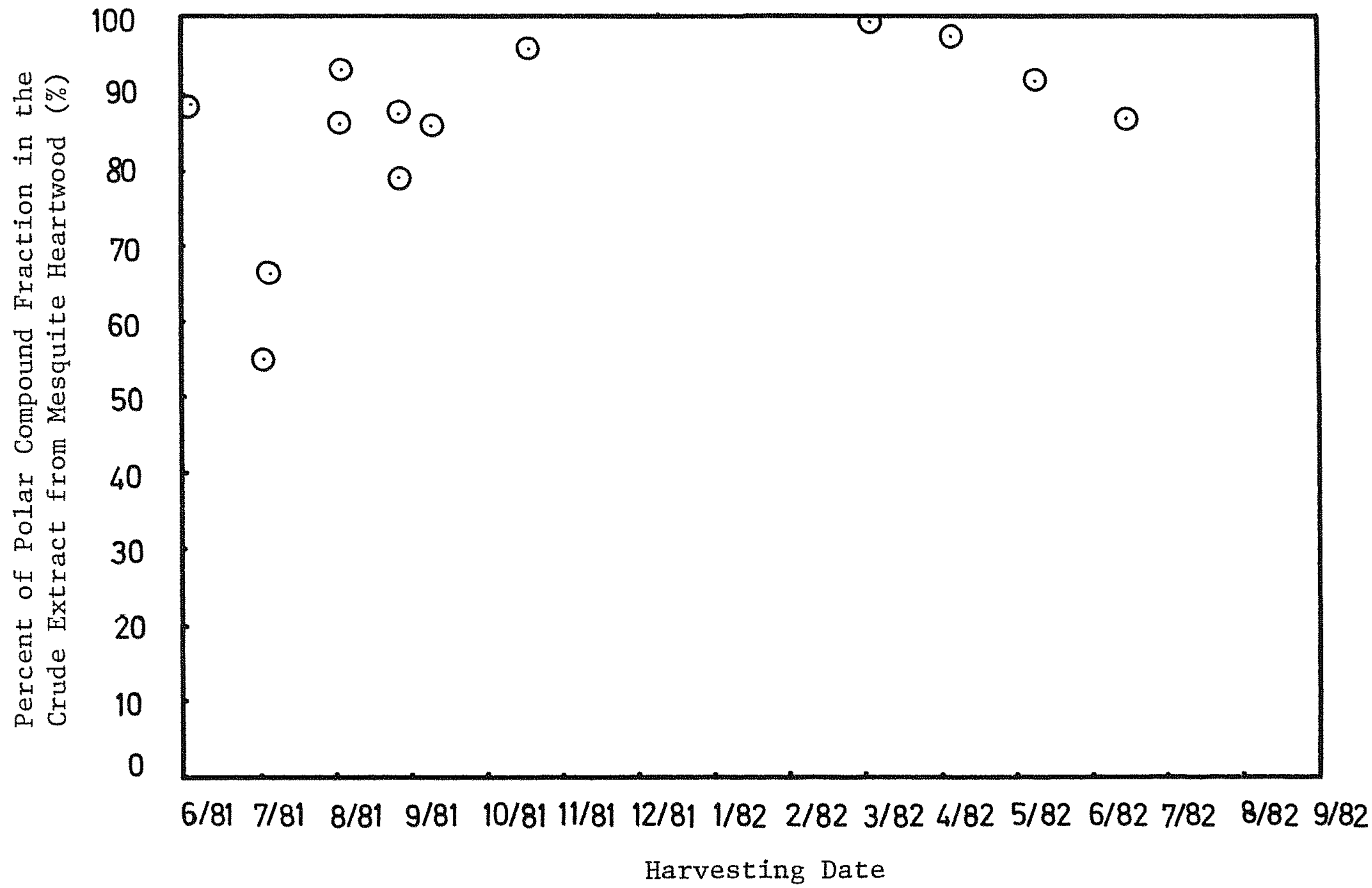
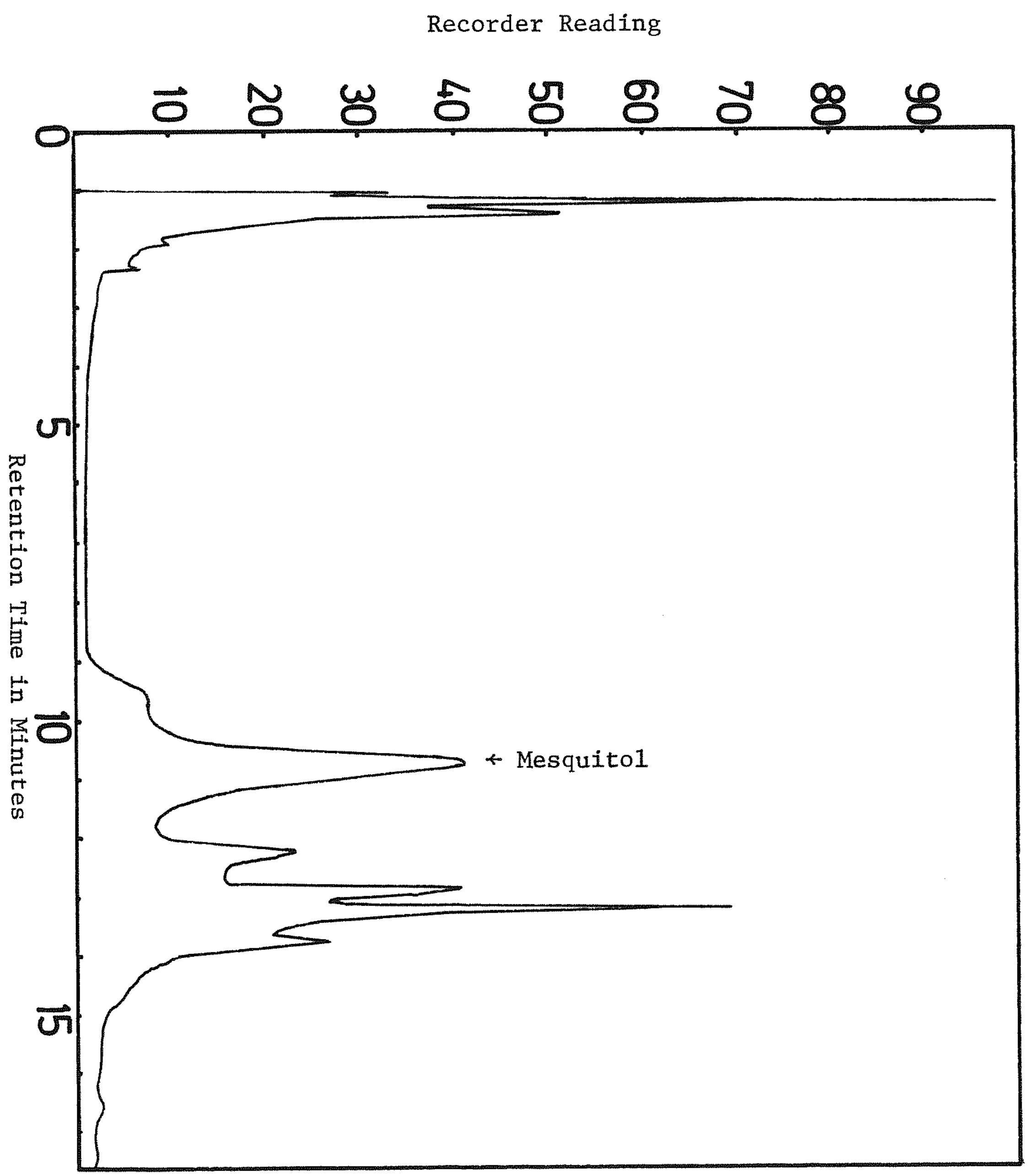


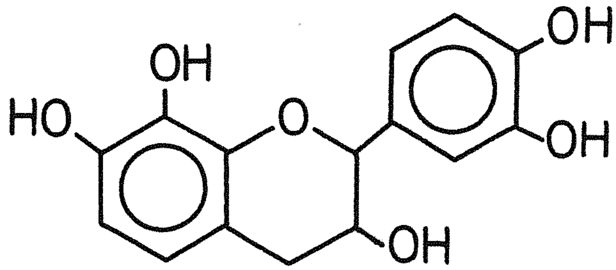
Figure 2. - Percent of Polar Compound Fraction in the Crude Extract from Mesquite Heartwood at Different Harvesting Dates

Figure 3. - High Pressure Liquid Chromatogram of Polar Compound Fraction



of Chen (1981). The major component of the polar fraction was separated by column chromatography. This compound was demonstrated to be pure by high pressure liquid chromatography.

By a combination of infrared spectral analysis, proton magnetic resonance spectral analysis, and elemental analysis (combustion) of this compound as well as proton magnetic resonance spectral analysis of a peracetylated derivative, the structure of the isolated compound was assigned as:



I

Due to the rather unique nature of this flavanol and the source, it was given the trivial name of "Mesquitol".

An intensive search of the chemical literature revealed only one previous report of this compound. Micyauchi, Yoshimoto, and Minami (1976) isolated compound I as a minor constituent of the heartwood of Piptadenia macrocarpa which is used in Japan for a fancy sliced veneer. Lack of generic relation of this species to mesquite makes the isolation of the same compound from the heartwoods of both species rather intriguing.

Data for the amounts of Mesquitol which were isolated from samples that were harvested at different times of the year are given in Figure 4. Except for material which was harvested during the winter months when the plant is dormant, 2 - 4 percent of pure Mesquitol may be obtained from the heartwood of mesquite.

During the course of isolating Mesquitol from the polar compound fraction, it was observed to undergo degradation when treated with acid or base or when exposed to sunlight. Although the decomposition products have not yet been identified, they are similar in chromatographic behavior to components other than Mesquitol which are present in polar compound fraction. This raises the possibliity that most of the polar compound fraction (and therefore the heartwood extract) may be composed of Mesquitol and closely-related compounds.

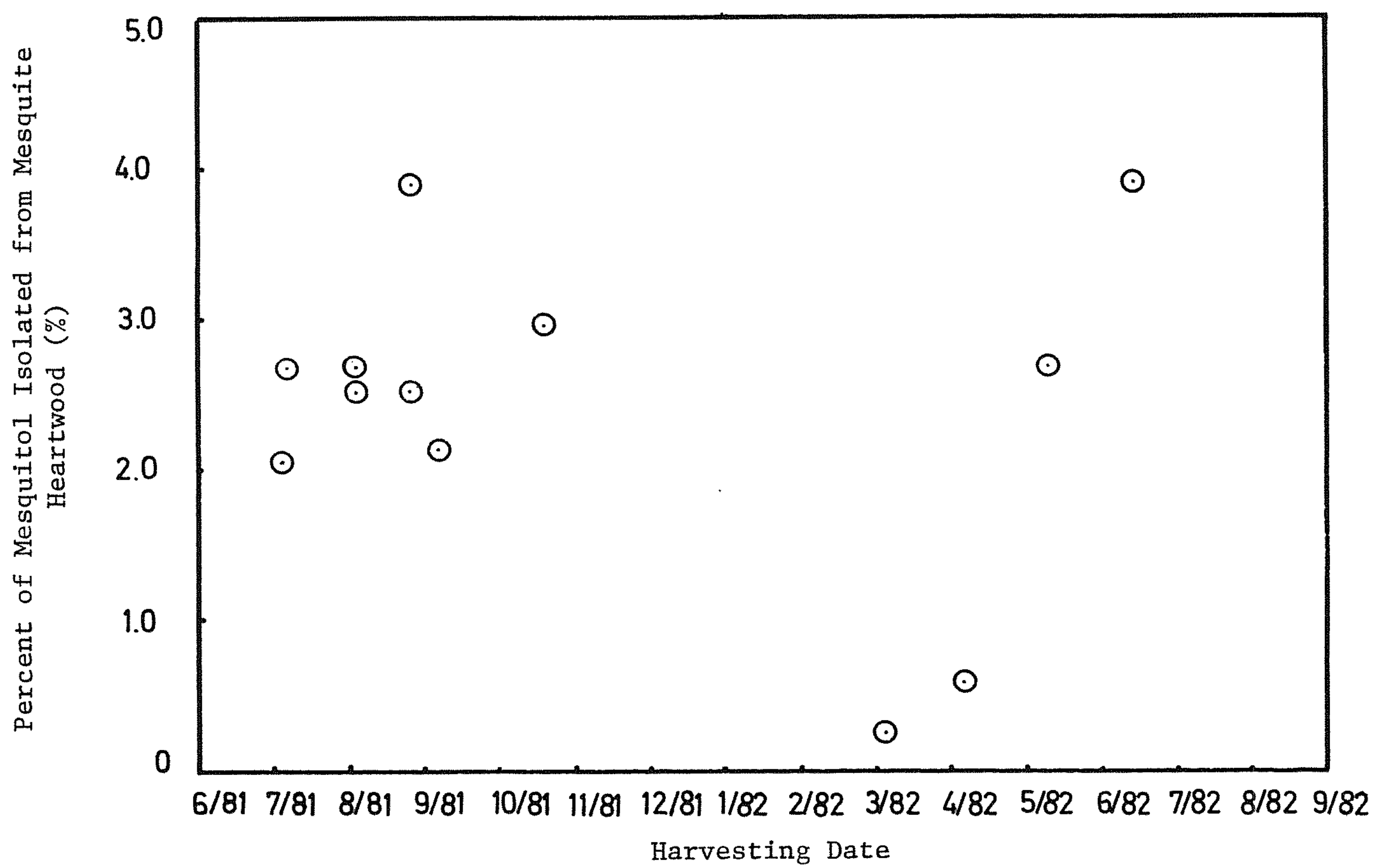


Figure 4. - Percent of Mesquitol Isolated from Mesquite Heartwood at Different Harvesting Dates

POTENTIAL USES OF MESQUITE HEARTWOOD EXTRACTS

It has been established that substantial amounts of Mesquitol and other poly-phenolic compounds may be extracted from mesquite heartwood. Therefore, potential uses of such materials can now be considered.

To test for useful biological activity of the extract, a sample of the polar compound fraction was submitted to the broad-based compound screening program of the Dow Chemical Company. This sample was sent before the photo-lability of Mesquitol was known. The failure to observe any useful biological properties may have resulted from photodecomposition of the material prior to or concomitant with the tests. Biological testing of pure Mesquitol under appropriate conditions to prevent its degradation remains to be done.

The high concentrations of poly-phenols in the polar compound fraction of mesquite heartwood extract may make this material suitable for the formation of new phenol-formaldehyde polymeric resins. This possibility will be examined in the near future.

LITERATURE CITED

Chen, S-J. R. 1981. Extraction of Organic Chemicals from Mesquite. Master of Science Thesis. Texas Tech University.

Goldstein, I. S., and Villarreal, A. 1972. Chemical Composition and Accessibility to Cellulose of Mesquite Wood. Wood Science, 5:15-20.

Miyauchi, Y., Yoshimoto, T., and Minami, K. 1976. Extractions from the Heartwood of Piptadenia species. Mokuzai Gakkaishi 22(1):47-50.

Ritter, G. J., and Fleck, L. C. 1922. Analysis of Some American Woods. Industrial and Engineering Chemistry 14:1050-4.

ECONOMICS OF POWER GENERATION SYSTEMS WITH MESQUITE[1,3]

Milton L. Smith[2]

Abstract.--An economic evaluation of a system for harvesting mesquite and utilizing it in a direct combustion electrical generating plant is presented. Costs for delivery of field dried mesquite at a central plant are $14.77/ton, and electrical energy costs are $.05/kwh.

INTRODUCTION

Mesquite utilization studies have examined many potential uses for this wood which generally is regarded as an undesirable growth. Several of these uses appear to be potentially feasible although additional research may be needed to complete the technical developments of the processes.

The process that likely has utilized mesquite to a greater extent than any other process is that of direct combustion. Mesquite was used as a source of fuel for heating and cooking by early settlers and currently is used as a fireplace wood. Direct combustion offers several advantages over other processes; first, direct combustion is a very simple process; and second, equipment is commercially available.

The paper concerns an economic evaluation of a system for harvesting, drying, transporting and direct combustion of mesquite to generate steam. This steam then can be used for industrial processes or for electrical power generation.

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[1] Paper presented at the Mesquite Utilization Symposium, Texas Tech University, Lubbock, Texas, October 29, 1982.

[2] Milton L. Smith is Professor of Industrial Engineering, Texas Tech University, Lubbock, Texas.

[3] This research was supported in part by line item funds provided by the Texas Legislature entitled "Research Funds in Mesquite Utilization."

HARVESTING, HANDLING AND TRANSPORTATION

Moisture in Mesquite

The moisture content of mesquite has an effect on virtually all phases of the system. Transportation costs depend upon moisture content since the density is a function of moisture content. Also moisture content affects combustion efficiency due to the need to vaporize all remaining water when the wood is burned.

At the time of harvest mesquite contains about 53% moisture. The actual level will vary with time of year and with recent climatic conditions. It will be highest when the plants are in full foliage.

Some form of drying will be necessary to reduce weight of the mesquite and to permit storage until the material is burned. This drying could be accomplished in the field under ambient conditions or at a central location where a drying facility is provided. In this paper the field drying approach was taken because the moisture is removed before the transportation occurs and also because expenditures on equipment and fuel at a central location are avoided.

Two approaches for drying mesquite were examined. These were to:

1. Dry in metal baskets
2. Dry in ricks

These alternatives require the harvester to accumulate mesquite chips in a hopper and to travel to a specified point and dump the hopper. The major operations performed prior to combustion are related to materials handling, and the type of equipment necessary depends upon the approach used in drying. It was assumed that a 28 day drying period will result in the mesquite having a 20% moisture content and a density of 9.38 pounds per cubic foot.

The metal baskets for drying were assumed to be constructed of angle iron and wire mesh. A basket has a capacity of 3.5 tons. Each basket will be used 12 times during a year. Basket cost was estimated to be $700. A lift truck will be used to move the baskets and to dump mesquite from a basket into a truck for transportation to a central point.

In the rick approach harvested mesquite is placed directly on the ground. A front end loader is required for loading mesquite into a truck. Harvesting costs are the same for the basket and rick approaches since the harvester must travel to some predetermined point to dump a full hopper.

Harvesting Costs

The mesquite combine developed by Dr. Willie Ulich (1980) at Texas Tech University forms the central part of the harvesting operation. A harvesting rate of 3.16 tons/hour was assumed. Tables I and II give cost data on the tractor and the combine units respectively. The total cost of harvesting was estimated to be $7.14/ton of green (53% moisture) mesquite and $10.81/ton of dry (20% moisture) mesquite.

Handling Costs

Costs associated with the field drying are considered here. After mesquite is harvested, it is allowed to dry for a 28 day period. Upon completion of drying it is loaded into a truck for transportation to a central point.

Handling Costs with Baskets

The baskets costing $700 each will hold 3.5 tons of green mesquite. The baskets will be left in the field until drying is completed and then will be dumped into a truck for transportation to a central point. Table III gives the cost data on the basket and handling costs. These costs total $6.65/ton (dry) for the basket, $.45/ton (dry) for basket spotting and $1.47/ton (dry) for the lift truck.

Handling Costs with Ricks

With the rick approach to drying mesquite the harvester dumps its hopper at a selected point such that a row is formed from the mesquite of successive dumps. The mesquite will remain in the rick until it has dried and then it is loaded with a front-end loader into a truck. This approach does not require labor or equipment as is needed in the approach discussed previously. Costs for this system are summarized in Table IV and are $1.25/ton (dry).

Transportation

Transportation of mesquite to a central location was estimated to cost $.85/mile. The cost for one-way hauls of 10, 20 and 30 miles will be $1.36, $2.72 and $4.08 respectively.

TABLE I. HARVESTING COSTS: TRACTOR

A. Fixed Costs

New 135 HP Tractor	$40,000
Estimated Salvage Value	4,000
Economic Life	10,000 hrs. (*)

(*)Economic Life of 3 years is considered; 3333 hours per year; two 8 hour shifts per day of 5.2 actual operating hours each.

Total annual cost: $16,067/year

B. Variable cost per 100 hours

Fuel consumption: 7.5 gal/hr (diesel)
Estimated price: $1.07/gal
Fuel cost: $803.00

Tire usage: 1.5 sets/year
Estimated cost per set: $1,000
Tire cost: $45.00

Oil and filter change; estimated as $25 every 100 hours
Oil and Filter cost: $25.00

General maintenance; estimated as $1500/year
Maintenance cost: $45.00

One operator required, at $5.00/hour
Operator cost: $500.00

Total variable cost per 100 hours: $1,418.00

C. Total cost per unit

Average cost production rate ranges from 4 to 6 tons/hour. Including transportation and dumping time, the average production rate yields 3.16 tons/hr. (green weight) - 2.09 dry weight tons/hour.

Fixed cost per unit time: $\frac{\$16,067}{3,333 \text{ hrs}} = \$4.82/\text{hr}$

Variable cost per unit time: $\frac{\$1,418}{100 \text{ hrs}} = \$14.18/\text{hr}$

Total Cost: $19.00/hr

Total unit cost (green weight): $6.01/ton

Total unit cost (dry weight): $9.09/ton

TABLE II. HARVESTING COSTS: COMBINE

A. Fixed costs

Cost of combine	\$28,000
Estimated salvage value	4,000
Estimated life	10,000 hrs

Total fixed costs: \$10,898/year

B. Variable costs

Knife sharpening every 2,000 green tons and other minor maintenance: \$1,000/year

C. Total costs: \$11,898/year

D. Production/year green weight:

3.16 tons/hr x 3,333 hours/year = 10,532 tons/year

Cost per unit: $\frac{\$11,898}{10,532 \text{ tons}} = \$1.13/\text{ton (green)}$

Production/year dry weight:

2.09 tons/hr x 3,333 hours/year = 6,166 tons/year

Cost per unit: $\frac{\$11,898}{6,966 \text{ tons}} = \$1.71 \text{ ton (dry)}$

TABLE III. BASKET AND HANDLING COSTS

A.	Basket Cost	
	Cost/basket	$700
	Life	10 years
	Maintenance	$50/year
	Utilization	12 times/year
	Capacity	3.5 tons (green)
	Basket cost	$4.39/ton (green)
		$6.65/ton (dry)
B.	Tractor and Trailer for Spotting Baskets	
	Cost	$10,000
	Life	5 years
	Maintenance	$1500/year
	Fuel	1.5 gal/hour
	Fuel cost	$1.07/gal
	Operator	$4.50/hour
	Operating rate	10 baskets/hour
	Cost	$.30/ton (green)
		$.45/ton (dry)
C.	Lift Truck Cost (18,000 lb truck)	
	Cost new	$60,000
	Salvage value	$20,000
	Life	7,000 hours
	Maintenance cost	$ 6,000/year
	Fuel consumption	4 gal/hour
	Fuel cost	$1.07/gal
	Operator cost	$5.33/hour
	Operating rate	10 baskets/hour
	Operating hours	2080 hours/year
	Cost	$.97/ton (green)
		$1.47/ton (dry)

TABLE IV. RICK HANDLING COSTS

Loader	
Cost new	$70,000
Salvage value	$10,000
Life	10 years
Maintenance cost	$ 5,000/year
Fuel cost	$1.07/gal
Fuel consumption	6 gal/hour
Operator rate	$5.33/hour
Operating rate	25 tons/hour (dry)
Operating hours	2080 hours/year
Cost	$1.25/ton (dry)

Total Cost for Harvesting, Handling and Transportation

Table V gives the costs for all operations for harvesting, handling and transporting mesquite. A 20 mile travel distance was used in the computations.

ELECTRICAL POWER GENERATION

The use of mesquite to generate electricity in a relatively small power plant is considered in this section. A system generating 4.5MW is the basis for the evaluation. All equipment described here is commercially available.

Fuel Requirements

Mesquite having a moisture content of 20% will be used as the fuel source. This material can be harvested for $14.77/ton with an average hauling distance of 20 miles. A payment to the land owners of $1.00/ton is assumed, giving a cost of $15.77 per ton. The net heating value at 20% moisture is 6584 BTU/lb. After hogging (a grinding operation) the density will be 15 pounds per cubic foot.

The plant is assumed to operate at 35% efficiency. Fuel requirements will be 8746 pounds/hour or 34,746 tons/year. A medium infestation of mesquite yielding 8.6 tons/acre (green) or 5.3 tons/acre (dry) will require 6.556 acres/year to supply an electrical power plant as envisioned here.

Burners and Boilers

Wood fired boilers are manufactured by several firms in the United States. We selected Industrial Boiler Company as a data source following recommendations by another boiler manufacturer. The Industrial Boiler Company Model 3-6500-300 has a steam output of 35,000 pounds of steam/hour at 410°F. It will handle fuel with up to 50% moisture. Estimated installed cost is $645,000 per boiler. A storage silo is recommended for each boiler; these silos contain 36,000 cubic feet and cost $90,000 each installed. This silo capacity provides fuel for a 10 day operating period.

Power Generation Equipment

Equipment for a 6MW power generation plant was obtained from the Crosbyton Solar Power Project (CSPP) office (Reichert, 1981). Since

TABLE V. TOTAL COST PER TON FOR HARVESTING, HANDLING AND TRANSPORTATION

	Drying Method	
	Baskets	Rick
Tractor	$ 9.09	$ 9.09
Harvester	1.71	1.71
Lift Truck	1.47	-
Baskets	6.65	-
Basket Spotting	.45	-
Front-end Loader	-	1.25
Transportation	2.72	2.72
Total Cost/Ton (Dry)	$22.09	$14.77

the CSPP system was very similar to the one considered in this paper, the CSPP equipment and cost estimates are utilized here. The 6MW plant is assumed to average production at 75% of capacity. Operating costs were estimated from EPRI Report AP-1403 (Albaugh, 1980).

Costs of Electrical Power

Table VI presents capital costs for the equipment; operating costs are given in Table VII with a total output of 39,420,000 KWH/year, average cost of electrical power will be \$.050/KWH.

DISCUSSION OF RESULTS

The estimated costs of mesquite harvesting, handling and transportation totaled \$14.77 per ton of material at 20% moisture. When this material is utilized for energy production in a 6MW electrical power plant, energy can be produced at \$.050/KWH.

Current rates of wholesale purchase of electrical power is slightly under \$.04/KWH. In July, 1982 the City of Lubbock purchased electricity from Southwest Public Service at \$.03927/KWH. Increasing costs of fossil fuel are expected to make electrical energy costs exceed \$.05/KWH by 1985 or 1986.

If is highly probable that the past trends of inflation of the prices of energy and other commodities will be maintained in the future. These trends have been such that energy costs increase at a higher rate than do other costs. If this situation prevails, a mesquite fueled power plant will become competitive with fossil fueled plants. Justification for this statement can be found in Tables VI and VII since the fixed costs are \$1,067,380/year and variable costs are \$907,605/year. Only the variable costs are subject to inflation, and these costs currently represent less than half of the annual costs.

All capital investments considered in this paper were amortized at 14% interest. No effects of investment tax credits or income tax deductions were considered. If a lower rate of interest had been used, the final results would have been much more attractive. For example, at 10% interest, power production costs would be less than \$.043/KWH.

TABLE VI. CAPITAL COSTS FOR 6MW GENERATING PLANT

Steam Generating Equipment	$2,860,000
Chipping Equipment (Grinder & Hogger)	75,000
Turbine Generator (6MW)	920,000
Heat Rejection System	117,000
Steam Condensing System	157,000
Feedwater System	88,000
Water Treatment System	500,000
Piping, Valves, and Insulation	590,500
Other miscellaneous equipment	100,000
Instrumentation and Control	537,000
Buildings and Foundations	1,480,000
On Site Handling Equipment	50,000
TOTAL CAPITAL COSTS	$7,474,500

TABLE VII. ANNUAL OPERATING COSTS

Fuel	$547,944
Maintenance	128,561
Direct Labor	105,100
Supervision	24,000
Insurance	23,300
Administrative and General	28,700
Utilities	50,000
TOTAL OPERATING COSTS	$907,605

Many industries in Texas are consumers of both electrical energy and steam. Such industries might find cogeneration of electricity and steam with mesquite as a fuel to be economically justifiable. When process steam is produced, almost all of the equipment in Table VI is required; the generation of electrical energy requires the addition of a turbine generator and somewhat higher capacity components. Economies of scale in sizing up the components result in total costs that are only moderately higher than those of Table VI.

In summary the feasibility of utilizing mesquite to generate electrical energy is marginal at current costs of electricity. However, if the cost of electrical energy increases at a rate that exceeds the general rate of inflation, a mesquite fuel system appears to have economic feasibility.

LITERATURE CITED

Albaugh, E.W., Collins, D.A. and Alescio, R.J., "Feasibility Study of Wood Residue-Fired Cogeneration at Heppner, Oregon," EPRI Report AP-1403, 1980.

Reichert, John D., "Summary of Capital Costs for Crosbyton Hybrid Plant," working paper, Texas Tech University, 1981.

Ulich, W.L., "Mechanical Harvesting and Primary Processing of Whole Mesquite," College of Agricultural Sciences and College of Engineering Report, 1980.

MESQUITE TO FUEL STEAM BOILERS FOR ENHANCED OIL RECOVERY [1,3]

Harry W. Parker[2]

Harvested mesquite has the potential to fuel steam boilers employed for enhanced petroleum production when heavy oil fields underlie significant stands of mesquite. In some cases one ton of green mesquite could aid the production of three barrels of oil. The equipment to harvest and burn the mesquite as an oil field boiler fuel requires some additional engineering and demonstration before a commercial scale enhanced oil recovery project could be implemented. The financial attractiveness of mesquite as an oil field boiler fuel will depend strongly on site specific facts plus a favorable regulations by governmental entities.

INTRODUCTION

Availability of abundant and economic sources of energy has been identified as an essential factor in the growth of Western industrial society. This culture provides the goods and services which we have all enjoy, and the leisure time in which to utilize them (Cottrell 1955). Petroleum and natural gas have displaced less convenient energy sources such as wood and coal in the twentieth century as the major source of energy. As a result, our domestic reserves of petroleum have been depleted to such a level where we are now capable of producing only portion of our nation's petroleum requirements and now must rely on imports. In 1977 imports accounted for 48% of the oil we consumed, but that figure has fallen to 30% due largely to reduced demand caused by higher prices and the recession (Beck 1982). Conservation and slightly increased domestic production have also assisted in the reduction of imports. Our nation's dependence on imported petroleum makes it difficult to maintain a favorable balance of trade and makes us vulnerable to supply interruptions caused by international political activities. To minimize these risks to national security and economic stability, it is desirable to develop additional domestic resources of liquid fuels. It has been almost a decade since the initial Arab oil embargo created considerable inconvenience and initiated a call for "energy independence". For a combination of political and economic reasons, we do not have significant commercial production of synthetic fuels, and cannot project a time in the future when our abundant re-

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serves of coal and oil shale will be utilized for large-scale synthetic fuel production. For the short term, more intensive production of domestic petroleum resources can moderate our dependence on imported petroleum. When it costs more to produce additional petroleum than to build synfuel plants then the economics will be favorable for commercial synthetic fuel production, if the manufacturer of synfuels is protected from excessive imports of less expensive petroleum (Parker 1979; Parker 1981).

Increased domestic petroleum production can be achieved by finding additional oil or economically producing a larger portion of the oil that has already been found. Producing additional oil from existing fields is termed enhanced oil recovery, and has considerable potential since we currently produce, on the average, only 30% of oil present in existing fields.

ENHANCED OIL RECOVERY

Initially, oil flows from wells or can be readily pumped from wells. Additional amounts of oil can be produced by injection of water or gas to result in producing an average of 30% of the potentially available oil as noted above. The fraction of oil which can be produced varies widely. Only 5 to 10% of the oil present can be produced if the petroleum has a very high viscosity. In some cases the oil is nearly a solid and none of it can be produced. These sources of oil are termed tar sands. The petroleum industry has recognized the potential of enhanced oil recovery and has developed a variety of techniques accomplishing the task. These methods include the use of solvents, surfactants, and elevated temperatures. Enhanced oil recovery is constrained by both the geological details of the oil reservoir and economics. Many recovery techniques which are very successful in the laboratory are very difficult to utilize economically in the field. Steam injection accounts for 77% of domestic enhanced oil recovery. This technique produces 288,000 bbl/day of oil or about 3.3% of our domestic oil production (Oil & Gas Journal 1982). Steam injection is particularly effective for high viscosity reservoirs. These high viscosity crude oils are usually referred to has heavy oils since they are more dense than normal petroleum. In some cases the oil is so dense that it does not float on water, but sinks. During the past 25 years techniques for steam injection have been developed and proven for production of these heavy oils in favorable circumstances. A recent publication reviews steam flooding technology and results (Farouq Ali & Meldau 1979).

Production of steam for injection into oil reservoirs requires considerable amounts energy. In the past natural gas was a convenient fuel for production of steam, but its increased cost and restrictions on its use for industrial applications has limited its availability. For this reason, frequently a portion of the produced petroleum is burned to produce the steam. In some cases 30% of the oil produced is consumed for boiler fuel. This oil could be conserved if alternative fuels were used for the boiler. In addition to conserving petroleum, burning solid fuels in steam generators used for enhanced petroleum production uncouples the cost of boiler fuel from the selling price of the oil produced. Therefore, increases in crude price would improve the economics of steamflooding more effectively if the fuel for the steam generation was not crude oil.

Primary candidates for boiler fuel are coal, petroleum coke, wood and agricultural residues. The options for using lignite or agricultural wastes to fuel steam generators has been evaluated in several reports sponsored by DOE. All of these reports were specific for California locations, but contain some information of general applicability (Author 1979; Gehron et.al. 1979; Shelton 1980) All of the available alternative fuels require greater investments in gathering, transportation, and combustion facilities than are required for burning oil or gas. In addition there are increased labor requirements for utilization of solid fuels. These increased investments and labor requirements must be offset by a sufficiently low cost for the solid fuel or these fuels will not be attractive for steamflooding. Wood and agricultural residues offer an advantage over many sources of coal and some crude oil of having a very low sulfur content. Low sulfur contents will avoid the need for stack gas scrubbing to meet emissions standards. Low ash content is another advantage of wood and agricultural residues over coal as a boiler fuel. Disadvantages of wood and agricultural wastes relative to coal include high moisture content, variable composition and availability, and widely dispersed sources. The agricultural residue of immediate concern is harvested mesquite. If mesquite were available on the land from which oil is being produced by steam injection, transportation and gathering costs for mesquite would be minimized.

POTENTIAL FOR UTILIZATION OF MESQUITE TO FUEL THERMAL OIL RECOVERY

In addition to the need for data on tar sand and heavy oil reservoirs data regarding the density of mesquite growth in Texas is required. This data should be in terms of tons of mesquite per acre, not percent canopy cover, the parameter frequently employed to characterize reduction in ranch productivity due to the presence of mesquite. In cases where heavy oil and mesquite are at the same location, the opportunity exists for utilization of mesquite as fuel for steam generators employed for enhanced oil recovery.

Even without specific location data it is possible to make estimates of the relative amount mesquite required to produce oil. On the average five barrels of water injected as steam are required to produce one barrel of oil (Farouq Ali & Meldau 1979). This is an empirical observation for 13 steam injection tests, and reflects oil prices and other economic factors at the time the data were obtained. Using an alternative fuel such as mesquite and changing economic factors could alter this average figure. In addition, the maximum amount of steam which can be injected profitably to produce oil will vary from site to site. This average steam requirement will be utilized to estimate how many tons of mesquite would be required to produce a barrel of oil. Harvested mesquite has an average heat of combustion of 6600 btu/lb and a moisture content of 20% (Smith 1982). If burned with 70% efficiency to produce 80% quality steam 0.35 tons of green mesquite would be required per barrel of oil produced. If a hypothetical oil reservoir which was 30 feet thick and contained 500 barrels of recoverable oil per acre foot were considered in a location where 20 tons of green mesquite were available per acre, the mesquite from 290 acres would be required to recover oil beneath one acre of land. All the data used in these calculations can vary significantly from location to location. This hypothetical example is given only as an illustration.

OPPORTUNITIES FOR STEAMFLOODING IN TEXAS

Texas produces 30% of our domestic petroleum. A recent survey lists only four steam injection projects in Texas (Oil & Gas Journal 1982). These projects are pilot tests or in rather small fields. In 1967 there were 35 steam injection and in situ combustion tests in Texas, but prior to the Arab oil embargo oil prices were quite low, so few if any of these projects reached commercial production (Oil & Gas Journal 1967). Figure 1 taken from that publication shows the locations of these early tests as an illustration of potential opportunities for thermally assisted petroleum production in Texas.

Professor Whiting's paper provides a more quantitative statement regarding heavy oil resources in Texas as shown in the following table:

Heavy Crude Resource (OOIP) in Texas Districts
(Millions of Stock Tank Barrels)

1	3,003.	7B	82.
2	4,789.	7C	126.
3	13,232.	8	127.
4	7,306.	8A	2,233.
5	267.	9	1,230.
6	1,813.	10	392.
		TOTAL	34,600.

In this table heavy crude refers to oil having an API gravity of 25 or less at surface conditions, and which is capable of flowing naturally at in commercial quantities at reservoir conditions. OOIP is original oil in place. Of this 34,600 million barrels of heavy oil originally in place in Texas 4,074 million barrels have been produced. Professor Whiting states that only 548 million barrels of the remaining oil are reserves which can be produced as of 1977. The difference, about 30,000 million barrels represents oil which could not be produced economically with known technology at that time. Much of this remaining oil can never be produced for a reasonable cost, but improved technology and increasing crude prices will make a modest portion of it available.
In addition, he estimates the tar sand resource in Texas at 140 million barrels and considers none of that to be producible reserves (Whiting 1979). The following paragraphs illustrate activities which might lead to actual production of a portion of that tar.

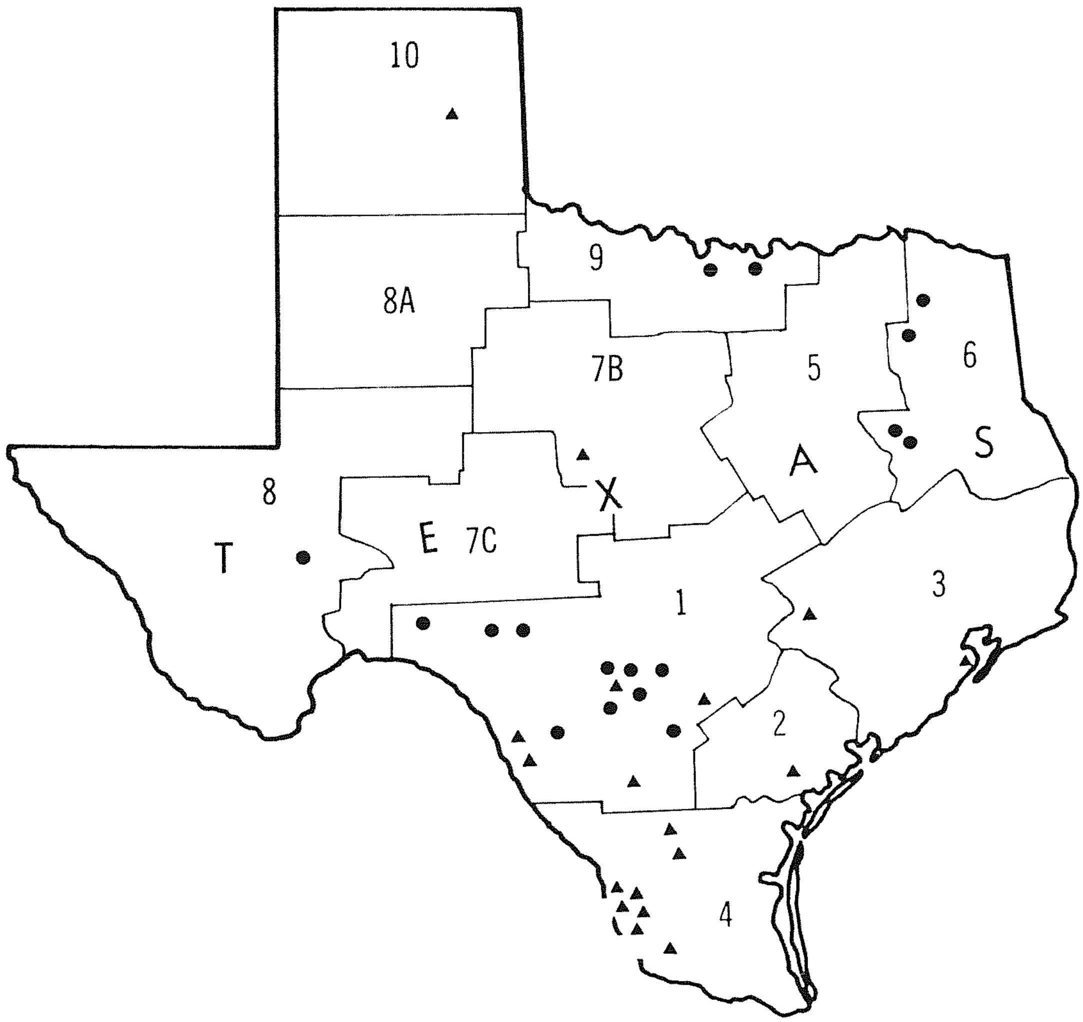

Figure 1 Texas Thermal Enhanced Oil Recovery
Projects Reported in 1967

The activities of Conoco in Mavrick County, Texas, about 125 miles southwest of San Antonio, will be considered as a specific example of potential tar production in Texas. Mavrick county was reported to have over 20% canopy cover by mesquite (Smith & Rechenthin 1964). Conoco has developed an enhanced oil recovery process which is particularly adapted to tar sands occurring at moderate depths. This process was successfully pilot tested during 1977 through 1980 (Britton et.al. 1982). A second larger project was started in August, 1981, and is in progress (Martin et.al 1982). The objective is production from the San Miguel tar sands in the Saner Ranch Field. These tar sands are at a depth of about 1500 feet and cover some 90 sections of ranchland, and contain 2 to 3 billion barrels of tar. This tar will require extensive refining to convert it to conventional products since it contains 10% sulfur and has an API gravity of -2. The two preceding references provide considerable details about the tests and the special Conoco process being utilized. Only aspects of the tests which pertain to utilization of mesquite for boiler will be reviewed here.

The Conoco pilot tests have indicated that about 10.9 barrels of steam are required per barrel of tar produced. This is two times as much steam as the average required for steamfloods in heavy oil. The greater energy requirements increases the desirability of using solid fuels for the boilers, not crude oil. A prototype fluidized bed boiler is being included as a part of the current test. The dual bed fluidized bed boiler was developed by Battelle Columbus Laboratories, and design and construction of the prototype was accomplished by Struthers Thermo-flood Corp, a supplier of oil-field steam generators (Davis et.al. 1981). The boiler includes provision for injection of limestone to remove sulfur dioxide resulting from combustion of high sulfur coal. A recent news article states that testing of the boiler has been quite successful. Present economic and tax circumstances are such that the Conoco project is not financially attractive for commercial expansion, (Wheatley 1982) but it is interesting to consider the scope of a possible commercial operation.

The paper by Conoco personnel states that a commercial project producing 10,000 barrels per day of tar would require 1,500 to 2,000 tons per day of solid fuel (Martin et.al.1982). This would be equivalent to about 5,000 tons per day of green harvested mesquite. To harvest this amount of mesquite 200 of the prototype Texas Tech mesquite combines would have to operate 8 hours per day. This investment, plus the investment required for trucks and auxiliary devises, would have to be economically justified with respect to the cost of burning coal or petroleum coke. The Conoco reference states that coal or coke are available in the area for $1.50 per million BTU (constant 1981 dollars). Dr. Smith's paper estimates that the cost of harvesting and delivering mesquite is approximately $1.12 per million BTU (Smith, 1982). These two data points suggest that harvested mesquite may be competitive with coal as fuel for oil-field boilers in some cases. Further calculations are needed to determine if both fuel costs have been estimated on a similar basis.

FACILITIES TO HARVEST AND BURN MESQUITE FOR STEAMFLOODING

Specialized steam generators have been developed for oil-field usage since the operating requirements are not the same as those employed in industrial boilers. Boiler water is used on a once-through basis so water treatment costs must be minimized. The water is partially vaporized in the boiler to simplify boiler design and minimize water quality requirements. Generators are expected to operate in remote location with a minimum of operator attention. Oil field steam generators are frequently relocated at one to five year intervals so they should be skid mounted. They normally produce about 50,000 pounds of steam per hour, and if larger amounts of steam are required, multiple units are installed. A steam generator designed or modified to burn mesquite would be most readily accepted by oil-field personnel if it were similar to steam generators using present fuels.

The fiberous nature of harvested mesquite would make it difficult to burn in conventional fireboxes. Fluidized bed combustion readily permits combustion of materials of this nature. In addition fluidized bed boilers would allow the harvested mesquite to be burned immediately after harvesting, without need for drying. A prototype oil field steam generator using fluidized bed combustion is being tested as discussed in the preceding section. These tests are being conducted using coal, but developers of the boiler indicate it can also be used for agricultural residues. This boiler employes two fluidized beds plus injection of limestone to remove sulfur dioxide from combustion gases to meet emission requirements when sulfur containing coal is burned. Less complex fluidized bed combustion units have been utilized in the wood products industry. They are a single fluidized bed in which the wood is gasified. Entrained ash is removed from the hot gases, and then the gases are burned in a modified boiler. A 1978 reference notes that 20 such units had been installed commercially at that time (Baston et.al 1978). There is sufficient experience with fluidized bed combustion to permit design of prototype mesquite fueled boilers.

The Texas Tech mesquite combine has been invented and tested on a limited scale. Dr. Ulich's plenary lecture at this symposium has discussed its performance and estimated costs for harvesting mesquite (Ulich 1982) This unit would require significant field testing to demonstrate its reliability and to correct any problems that further testing may disclose.

FACILITATING USE OF MESQUITE TO FUEL OIL-FIELD BOILERS

Many tasks must be completed to make a comprehensive evaluation of the potential of mesquite as a fuel for oil-field boilers. In those cases where the use of mesquite appears attractive, even more work will be required to implement its utilization. These tasks will be briefly discussed.

A list needs to be prepared of those locations in Texas where a potential exists for enhanced oil recovery by means of steam injection and the quantity of mesquite available as potential fuel for steam generators. Less information is available regarding potential yields of mesquite at specific locations. Detailed data should be developed only for the most attractive potential locations.

A considerable technological base exists for design of oil-field steam generators, and for the combustion of biomass in boilers. This technology can be utilized for evaluation of different boiler types. Before a commitment is made for commercial operation of a particular boiler design a prototype boiler should be tested. The Texas Tech mesquite combine has been subjected to limited testing. Additional testing is required which may lead to improvements in the machine. Both of these equipment design, construction, and testing tasks will require significant engineering efforts and financing.

The economics of using mesquite as a boiler fuel can become quite complex since there is not an existing market for mesquite as a boiler fuel. The economic evaluations will have to consider value of mesquite removal in terms of improved ranch productivity as well as the value of mesquite as a fuel. Alternative fuels such as coal, and alternative methods of mesquite control such as herbicides will have to be compared to harvesting and burning mesquite. Persons with a long-term interest in ranchland productivity should search for additional ways to improve the economics of mesquite utilization. The economic advantages regarding tax breaks or interest rates which might be available to rancher owned cooperative mesquite harvesting companies or to the formation of a "mesquite disposal district" should be evaluated. Cogeneration of electricity at the oil-field boiler site should be considered. Electricity produced during cogeneration may be less costly than conventional generation as reported in the previous paper (Smith 1982), since the energy normally lost to the condenser will be utilized as steam to inject for oil recovery. Stable oil prices, and defining produced tar as a "synfuel" could be an essential factor in making some enhanced oil recovery projects attractive. Additional legislation might be required to implement some of these techniques to improve the economics of mesquite utilization and of tar or enhanced oil recovery.

The engineering, financial, legal and social activities required to develop the infrastructure necessary to utilize mesquite as a fuel for oil-field boilers are varied and complex. No one existing organization such as an oil company, rancher, or equipment manufacturer may have sufficient incentive to take the lead in building this infrastructure. If this proves to be the case it may be helpful for the state government to assume a significant responsibility in planning and demonstration projects.

CONCLUSIONS

The opportunity to utilize one ton of green mesquite for the production of three barrels of petroleum may exist in several locations throughout Texas. This objective is accomplished by using the mesquite to fuel boilers which generate steam to be injected into heavy oil reservoirs to cause increased oil recovery. In doing so ranchland productivity would be increased and the necessity to import petroleum decreased. Realization of this goal will require planning and completion of the activities discussed in the preceding section of this paper.

REFERENCES

Authur G. McKee & Co. 1979. Coal-an alternate fuel for thermal enhanced oil recovery steam generation. SAN/2418-1. U.S. Dept of Energy.

Baston, V.F., L.G. Gale, W.L. Hurt, J.W. Stallings, and C.M. Young. 1978. American Chemical Society Meeting, Sept 12, 1978.

Beck, R.J. 1982(Jl,26). U.S. oil demand to fall again. Oil and Gas Journal, pp 175-204.

Britton, M.W, W.M. Martin, R.J. Leibrecht, and R.A. Harmon. 1982. The street ranch pilot test of fracture-assisted steamflood technology. Society of Petroleum Engineers Paper No. 10707. Presented at California Regional SPE Meeting, San Francisco, March 24-26, 1982.

Cottrell, W.F. 1955. Energy and society. Reprinted in 1976 by Greenwood Press, Westport, CN.

Davis, J. S., W.W. Young, and C.J. Lyons. 1981(Jn,8). Use of solid fuel possible for field steam generation. Oil and Gas Journal. pp. 129-134.

Farouq Ali, S.M. and R.F. Meldau. 1979. Current Steamflood Technology. Journal of Petroleum Technology, pp. 1332-1342.

Gehron, B.W., H.M. Kosstrin, and R.K. McDonald. 1979. Potential use of wood and agriculture wastes as steam generator fuel for thermal enhanced oil recovery. SAN/1038-PO-1. U.S. Dept. of Energy.

Martin, W.L., M.W. Britton, and R.A. Harmon. 1982. Conoco's South Texas tar sand project. Second International Conference on Heavy Crude and Tar Sands, Caracas, Venezuela, February 12, 1982.

Oil and Gas Journal. 1967(Oct, 2). Thermal-recovery operations mushroom across Texas. pp. 60-61.

Oil and Gas Journal. 1982(Ap,5). Steam dominates enhanced oil recovery. pp.139-159.

Parker, H.W. 1979. Petroleum--its future among alternative energy sources. Southwestern Petroleum Short Course Association, Texas Tech University, Lubbock, Texas.

Parker, H.W. 1981. A synfuel trade-off plan could trim oil imports. Washington Star p. A-14, May 25, 1981.

Parker, H.W.(ed.). 1982. Mesquite Utilization-1982. College of Agrilcultural Sciences, Texas Tech University, Lubbock, Texas

Shelton, R., A. Shimizu, and A. Briggs. 1980. Potential use of California lignite and other alternate fuel for enhanced oil recovery. SAN/2157-1. U.S. Dept of Energy.

Smith, H.N. and C.A. Rechenthin. 1964. Grassland restoration the Texas brush problem. USDA Soil Conservation Service, Temple, Texas.

Smith, M.L. 1982. Economics of power generation systems with mesquite. In (Parker, 1982).

Ulich, W.L. 1982. Economics and technology of harvesting whole-tree mesquite. In (Parker, 1982).

Wheatley R. 1982(Ag 16). Conoco assesses heavy crude pilot. Oil and Gas Journal, pp. 66-67.

Whiting, R.L. 1979. Heavy crude oil and tar sand resources and reserves of the United States emphasis on the state of Texas. The United Nations First Conference on the Future of Heavy Crude and Tar Sands, Edmonton, Alberta, Canada, June, 1979.