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"ALTERNATIVE LIQUID FUELS FOR SOUTH AUSTRALIA"

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1. INTRODUCTION

Following the oil price rises in 1973, the subject of an "energy crisis" has been much to the fore of public discussion. But it it not realistic to talk of a general energy crisis in Australia at the present time, since there have been few, if any, shortages of electricity, natural gas or even liquid transport fuels. Indeed, even the price of energy in real terms is about the same or slightly less than it was 10-15 years ago. However, this situation cannot last and shortages of energy will emerge in future years in different areas and for particular energy types.

South Australia uses mainly Cooper Basin natural gas and Leigh Creek coal for generating electricity in its installed and planned power stations. Natural gas fuelled about three-quarters of the electricity generated in South Australia in 1978-79, but the use of natural gas for this purpose is expected to peak in the early 1980's and decline thereafter.

Further supplies of coal from Leigh Creek, committed to the existing and new power stations at Port Augusta, will become increasingly expensive as mining extends to greater depths. Other deposits of coal are being evaluated to determine their ability to supply future demands, but whilst the size of reserves is more than adequate, problems associated with location, geological structure, overburden, groundwater and combustion characteristics need to be overcome before their development would be undertaken.

Although the proven gas reserves of the Cooper Basin are not sufficient to supply Adelaide beyond 1987 after allowing for the Sydney market's requirements, the presently "inferred" reserves are likely to be proven to enable supply beyond the year 2000.

There is, however, an urgent need for more exploration and appraisal drilling to confirm these supplies, and the Government has established an accelerated exploration programme for this purpose.

The most immediate source of concern is oil, in which Australia's forecast consumption to 1990 is twice the presently known reserves. Whilst 50 percent of energy in Australia is consumed as oil, only 1 percent of the total fossil fuel reserves are oil. Australia currently imports about 30 percent of its oil requirements and this is expected to rise to 50 percent in the 1980's with continuous deterioration thereafter.

World-wide oil production is expected to peak around 1990, and thereafter continue to fall. Oil's share of total primary energy used in the world is expected to decline from the present 40 percent to about 10 percent by the year 2020. This tightening long-term supply of oil is the major factor of concern for future energy supplies, which coupled with short-term fluctuations in supply, will make the problem of liquid fuels increasingly apparent through the eighties and nineties. Nevertheless, it is essential to recognise that petroleum-based fuels will not suddenly disappear and indeed they may even increase in supply for some years to come (subject to the supply policies of the oil-exporting countries) before production starts to decline.

This specific problem of liquid fuels can be minimised, delayed or overcome by programmes of conservation, substitution, identification of new sources of fuel or the development of new technology using alternative energy sources of liquid fuels. Such programmes, whilst applicable to, and necessary for, all sectors of the economy, can be most effective in a number of sectors heavily dependent on liquid fuels. Table 1 shows consumption of energy by industry sector in South Australia in 1976-77, and indicates that two sectors (transport and industry) accounted for 75 percent of the petroleum products used in this State. Clearly, major savings of liquid fuels in these sectors can result in a significant reduction in the total requirements for such fuels.

Motor spirit accounted for 46 percent of petroleum use and diesel oils 32 percent. However, as shown in Table 2, these fuels accounted for 99 percent of petroleum fuel used in agriculture, which is equivalent to 95 percent of total energy used in agriculture. Hence agriculture is particularly susceptible to shortages of these products.

In considering the suitability of alternative fuels as replacements for petroleum-based fuels, it is important to recognise the difficulty of changing the pattern of energy use because of the inherent inertia in manufacturing and infrastructure. Because of this, alternative fuels need to be reasonably compatible with existing vehicles, machinery and facilities if they are to be acceptable, at least in the short and medium term. In addition, it is necessary to consider whether the alternative fuels will be used alone to replace petroleum-based fuels from certain functions, or whether they will be blended with such fuels so as to spread their availability over all existing and potentially new functions.

2. FOSSIL FUEL OPTIONS

In the immediate future, policies to replace petroleum-based fuels with other fossil fuels are most likely to be effective and will provide a period of time in which longer-term alternatives can be assessed and their use planned for and adopted.

The most immediate alternative fuel is LPG, of which considerable quantities are presently exported from Australia and supplies are likely to increase when Cooper Basin liquids and North West Shelf developments commence. Although the use of LPG as a transport fuel is not a viable alternative for all transport modes and all locations, it has the potential to replace perhaps 10 to 15 percent of motor spirit requirements (particularly for capital city based vehicle fleets).

An alternative means of reducing consumption of liquid hydrocarbon fuels in transport through the substitution of other more plentiful fossil fuels is the use of electric vehicles. The potential for these vehicles to make a significant contribution to a reduction in demand for liquid fuels is not great, but nevertheless they can offer a reasonable alternative for certain locations and functions.

As conventional supplies of oil become more expensive (as supplies decline and previously uneconomic and inaccessible reserves are exploited) the economics of exploiting unconventional sources of fossil fuels such as tar sands, oil shale and synthetic oil produced from coal should also improve. Nevertheless, this is not a simple option as the technology involved is still uncertain and extremely expensive. Without some major technological advances in these processes, they are unlikely to be competitive until the price of crude oil increases significantly above present levels, and even then their contribution will be small. In addition, the environmental effects of all these processes and their water requirements are significant obstacles to their development.

One process based on coal for which technology is available and price competitive is the production of methanol or methyl-fuel. Methanol could be produced from Australia's plentiful supplies of low quality coal, and eventually from wood or wood residues whenever coal supplies become exhausted. The current world price is about 10 cents per litre, and estimated costs of production from coal in new plants are of a similar magnitude. This compares to the current ex-refinery gate price of motor spirit of 19 cents per litre (see Table 3).

A litre of methanol has a heat value of 15.6 MJ, or only 46 percent that of a litre of premium gasoline. Theoretically therefore, consumption of methanol per kilometre travelled should be about double that with gasoline. Its research octane number, however, is 110 (compared to 98 for gasoline) or 123 when used as a gasoline blend, and this property with others which raise engine efficiency, means that volumetric consumption might only be about 50-60 percent higher. This raises its present gasoline equivalent price to about 16 cents/litre equivalent, making it already price competitive as a fuel additive. Its high octane number also offers advantages of reducing lead contents or reforming severity of petroleum gasoline. Its ability to produce power over a wide range of mixture strengths and its high latent heat of vaporisation minimizes tuning and durability problems. An engine to run on pure methanol must have a very high compression ratio, a modified carburettor and a pre-heat system. Similar to the present LPG conversion kits, there is little reason why a methanol kit incorporating these modifications could not be supplied, and it would greatly improve alcohol fuel economy.

In the manufacture of methanol, the output of the plant can be increased by 50 percent if small amounts of other alcohols can be tolerated in the product. Such a mixture, called methyl-fuel contains more energy per unit volume than methanol because of the presence of ethanol, propanol and iso-butanol. It can be produced in larger quantities at a lower price than pure methanol, it has improved water tolerance properties and in general, is a superior fuel.

Tests by major car manufacturers such as Volkswagen, Fiat and Chrysler indicate no major problems with methanol based fuels. A number of countries, including New Zealand, have indicated support for a methanol fuel option. In the immediate future, use of Australia's vast low-quality coal deposits or natural gas from the North West shelf could provide considerable quantities of methanol or methyl-fuel at a total capital cost much less than other alternatives. For example, it has been estimated that the capital costs of facilities to produce the heat value equivalent of the 14 million kilolitres of petrol consumed in Australia each year would be about $5 000 million for methanol from natural gas

($10 000 million from coal) but almost $20 000 million for ethanol. In the longer term, supplies could be derived from special plantations of fast growing trees.

3. NON-FOSSIL FUEL OPTIONS

Indeed, it is to be expected that an increasing proportion of energy requirements will be derived from non-fossil sources. Solar energy can be used for direct heating or for electricity generation using wind, hydro-electric or thermal units. In such uses, it can replace some requirements for liquid fuels in space heating or through electric vehicles in transportation, but this will not represent a major alternative source of energy.

The major future non-fossil sources of energy are likely to be derived from the quantum collection processes of solar radiation, namely photo-electrics, photo-synthesis and photo-chemistry. Whilst the ability to produce electricity direct by photo-electrics is an exciting development and one in which costs are likely to fall in the coming years, it has little relevance to a consideration of alternative liquid fuels and will not be considered further in this paper.

The processes of photo-chemistry and photo-synthesis store energy in plant matter which can be recovered for use as a fuel. It has been estimated that these processes store in plants 10 to 15 times the energy used throughout the world, and it is to these processes that Australia must look for part of its future fuel supplies (especially with its access to large areas of land with high incident solar radiation). As this is of particular relevance to agriculture, it is this aspect which I wish to examine in more detail in this paper.

There appear to be three major types of liquid fuels derived from agricultural products which would be feasible replacements for petroleum: pyrolysis oils, alcohol fuels and hydrocarbons from plants. As other speakers intend to address themselves to the question of alcohol fuels, and as it is unlikely that pyrolysis oils would be price or quality competitive when based on agricultural waste, I will concentrate only on the subject of hydrocarbons from plants.

3.1 Hydrocarbon Producing Plants

Plants use solar energy to produce a wide variety of products. The photo-synthetic cycle of the green plant produces carbohydrates, which are compounds of carbon, hydrogen and oxygen. However, the process can be carried one stage further to produce hydrocarbons which contain only carbon and hydrogen.

At the present time, considerable research is being undertaken on processes to convert plants to fuels, such as ethanol from starch, sugar and cellulose, or methanol and pyrolysis oils from wood and other cellulose products. However, the growing of plants for secondary conversion to fuels should be expected to be less attractive than the direct production of hydrocarbons from plants, because of the increase in processing energy requirements and costs.

A more detailed understanding of the photo-synthetic process has stimulated experiments in recent years on the use of plants to produce hydrocarbons that could substitute for petroleum. The ability of plants to produce hydrocarbons has been known for a long time, as witnessed by the commercial production of hydrocarbons including terpene resins, waxes, tannins, vegetable oils, eucalyptus oil and other essential oils. The major product in this category, however, is natural rubber produced from *Hevea brasilensis*.

Hydrocarbons in plants are usually stored in the form of an emulsion in water known as a latex. The latex from *Hevea* has the same type of chemical composition as petroleum, although it has a somewhat different atomic arrangement and different molecular weight. If the molecular weight of the *Hevea* hydrocarbon could be kept down to below 50 000 instead of the present 500 000 to 2 000 000, the result could be an annually renewable fuel tree.

There are over two thousand species of plants which produce rubber or hydrocarbons, some of which might be useful for producing materials which could be used as alternative fuel and material sources. One such species, *Euphorbia*, produces significant quantities of a latex containing about one-third hydrocarbon. These hydrocarbons are similar to those produced by *Hevea* but are much lower in molecular weight (50 000 or less).

The U.S. Department of Agriculture has already evaluated about 300 species and selected 30 for further research. The eight leading contenders were reported to include poinsettia, milkweed, guayule and goldenrod. Trial plantations have commenced in the U.S.A. of *Euphorbia lathyris*, *Euphorbia tirucalli* and *Euphorbia coerulescens*. Two Japanese companies, Nippon Oil and Sekisui Plastics, have cultivated plantings of *Euphorbia tirucalli* in Japan since 1978. Diamond Shamrock, a U.S. company, has planted sizeable plantations of *Euphorbia lathyris*, and considerable interest has been awakened in evaluating the performance of earlier Euphorbia plantations in a number of countries, including *Euphorbia resinifera* in Morocco.

The latex in these plants comprises a mixture of resins, gums, hydrocarbons, sugars and other substances, and is usually formed in special cells known as lactifers. Rubber occurs in the latex as microscopic droplets in colloidal suspension in an aqueous medium. The significance of the latex and its use to the plant is unknown. The proportion of rubber, resins and other compounds varies between the different species, and yields also differ.

The main hydrocarbon compounds present in the latex are rubber and terpenoid resins. These resins are highly reduced organic compounds with an energy content, in terms of heat of combustion, greater than that of crude oil (see Table 4). Since other photo-synthetic products such as cellulose, starch and sucrose have less than half this energy content, the terpenes and steroids are attractive in terms of potential energy per unit weight. Further, since the mixture of chemicals is so complex, it is likely that a simple fuel-making process will be preferred to an attempted separation of valuable chemicals.

To make motor fuel from this crude mixture would require conversion of olefinic unsaturation into aromatic ring compounds or hydrogenated compounds. As such, it is more likely that such oils would be better suited to diesel fuels than gasoline. Since alternatives to diesel fuel have not been developed, and as the alcohol fuels suited for petrol engines are generally unsuitable for diesel engines, a combination of diesel oil from the latex and alcohol fuel from the plant biomass could provide for both petrol and diesel requirements (the dry weight of bagasse would be 2 to 5 times the weight of resin). In addition, some lighter hydrocarbons could be recovered by distillation of the crude oil.

Although little attention has yet been given to extraction and processing techniques for Euphorbia species, it is likely that processes similar to sugar cane processing will be used with shredding and crushing to extract the latex. The products from such plants would include whole-plant oils, rubber, gutta (a latex usable in plastics manufacture), cellulose for paper or alcohol production and waxes.

Estimates of yield and cost of production are obviously uncertain at this stage, and will not be reliable until trial plantation and pilot plant results are evaluated. A 1977 estimate for Euphorbia lathyris indicated yields of resin of about 1100 kg/hectare/year (or about 8 barrels). However, 1979 results from trial plantations indicated yields of 10-20 barrels per hectare per year for Euphorbia tirucalli and 20 barrels per hectare per year for Euphorbia lathyris. These yields of up to 2 tonnes per hectare per year are already similar to yields of rubber from Hevea, although little work has yet been undertaken on genetic improvement or agronomic practices.

Estimates of agricultural cost of production have been put at about $900 per hectare per year for a hypothetical plantation of 5000 hectares. In addition, there would be the cost of extraction and processing of the latex which could be estimated by reference to rubber processing plants or to sugar cane processing mills. On this basis, allowing only for credits to resin recovery (ignoring rubber, cellulose and wax receipts), a cost of the order $60-70 per barrel would result. However, allowing for recovery of 1 tonne per hectare of rubber at a value of $700, this cost would drop to approximately $30 per barrel.

The Standard Oil Company of California and the Stanford Research Institute have independently costed oil produced in small (1000 barrels per day) plants at US$66 per barrel based on present yields. With larger plants (100,000 barrels per day) they have estimated this cost is likely to fall to US$20 per barrel, similar to the current oil prices. These estimates did not include credits for by-products.

On these preliminary figures, it can be seen that the economics of producing hydrocarbon oils from plants appears sufficiently attractive to justify research in Australian conditions.

In 1945, the yield of natural rubber from Hevea was about 300 kg/hectare per year. With a program of genetic development, these yields were raised to over 3000 kg/hectare per year within 30 years. Only a three to five-fold total yield improvement (say, two-fold increase in biomass and two-fold increase in hydrocarbon content) is needed to make many of the above species as productive as the Hevea tree. Already, H. Yokoyama of the USDA has reported a three-to-four fold increase in rubber yield from guayule by treatment of young plants with a chemical bio-inductor (2-(3,4-dichlorophenoxy)-triethylamine) which stimulates hydrocarbon production. He reported that similar yield improvements could be expected with Euphorbia and other species. Such yield increases would significantly improve the economics of these plants.

For commercialisation, a high growth rate is desirable and this generally depends on the amount of water and nutrients available. Arid zone plants, although able to grow and survive in areas of low rainfall, tend to have low growth rates unless stimulated by supplementary irrigation. However, it has been found that although plant biomass may increase with such irrigation, the hydrocarbon content may remain the same, and thus there may be few benefits from it. An arid-land, non-irrigated crop every few years may be preferable and more economic than an irrigated crop every year.

An extensive research and development programe is needed to select preferred plant species, to improve them genetically and to develop their agronomy. South Australia (through the Waite Institute) undertook such a program in the period 1941-45 on guayule, and detailed reports exist on the performance of this plant in this State. Although many agriculturalists have argued against the potential of this crop, recent developments in the demand for and supply of rubber, the recognition that the resins could be used as a high value fuel and improvements in agricultural technology (such as reported above) suggest that guayule and other hydrocarbon plants are worthy of investigation for growing in selected areas of this State.

Given the requirement for plants with high natural growth rates, it is likely that such plants will be the shrubby herbaceous annuals or biennials which develop from seed to maturity in a short time. In addition, mechanised harvesting would favour an erect, bushy plant which could be planted in rows and either cut above ground or pulled up entirely by a harvesting machine. Guayule and *Euphorbia lathyris* are plants satisfying both these requirements. However, in view of the availability of better statistics on guayule production, in the following Section the economics of a guayule industry in South Australia will be examined.

. Guayule

A detailed description of the history of guayule rubber production and the characteristics of the plant is given in Appendix 1. Its main advantage, as with most of the hydrocarbon-producing plants, is its ability to be cultivated on marginal soils which are not suitable for crop production. It thus offers the possibility of using presently un-utilised land for agriculture or providing an alternative crop for farmers in the marginal wheat belt area, the Mallee, the Riverland or on Kangaroo Island.

However, the main question to be resolved is whether guayule can be grown economically at the present time. One of the major expenses in guayule production is the cost of establishment of plantations. The cost of seedlings produced in a nursery could vary from between $10 to $20 per thousand, which at a spacing of 70 x 60 centimetres or 28 000 seedlings per hectare could cost $20 to $560 per hectare.

It has been estimated that a minimum economic plantation of guayule might be about 4 000 hectares, which on a four year rotation basis would require 1 000 hectares to be planted each year and be sufficiently large to enable the construction of an extraction factory in the centre of the fields. The harvest from 1 000 hectares each year would be approximately 25 000 tonnes of fresh shrub at an age of 4 years.

A manager and several workers with seasonal employees would be required to work the fields. The additional temporary help would be required at cultivation and planting. For planting seedlings, total costs of $120 000 have been allocated in Table 5 for cultivating, planting out and caring for 1 000 hectares of plants. In the second and following years, the costs of maintaining this field have been assumed to decrease to $70 000 and $60 000 respectively. Land rent has been fixed at 10 percent of the assumed cost of $300 per hectare, and $20 000 per 1 000 hectares has been allowed for other miscellaneous overheads (weedicides, irrigation, etc.).

When harvesting is done with heavy machinery for digging and baling, the cost would be expected to be relatively low. Allowing for the depreciation and operating cost of such machinery and labour costs, a figure of $50 000 per 1 000 hectares has been set in Table 5.

Table 6 shows that the estimated agricultural cost for a crop is $670 per hectare in the establishment year and totals $1 060 per hectare over the four year growth period, an average of $265 per hectare per year. Table 6 shows the annual operating cost during the initial period in which 1 000 hectare plantings are commenced over a period of 4 years. This cost compares reasonably well with a US 1961 cost estimate of $750 per hectare over a 4 year period.

With projected yields of 25 tonnes of fresh shrub per hectare at the age of 4 years, and with yields of products per fresh shrub tonne as indicated below, the annual production of rubber would be approximately 2 500 tonnes and of resin 1 250 tonnes.

It should be noted that this yield of rubber is equal to approximately 20 weight percent based on dry weight of plant, a yield already achievable with existing guayule strains. Clearly, with improvements in yield as a result of the development of better varieties and agricultural techniques (including the use of bio-inductors) this production level should be significantly improved.

	Yield (Tonne per Tonne of Fresh Shrub)	Annual Production (Tonnes)
Rubber	.10	2 500
Resin	.05	1 250
Bagasse	.25	6 250
Leaves	.10	2 500

Using a conservative value of $1 per kilogram for rubber and $150 per tonne for the resin (equivalent to a crude oil price of $20 per barrel) indicates an annual value of production of approximately $2.7 million, ignoring any possible credits for bagasse, waxes or seeds.

The costs of milling are uncertain, but reasonable comparisons could be made with the cost of sugar cane milling. An estimated staff of 10 people would be required to run an automated extraction factory operating on a continuous basis, with estimated labour costs $200 000 per annum. With the use of some of the bagasse for providing heat for the processing, total operating costs would be of the order $400 000 per annum. Allowing $10 million for the construction cost of the plant depreciated over 20 years, gives total processing costs of $900 000 per annum, as shown in Table 7. Thus the cost of cultivating and processing guayule is estimated to be $1 960 per hectare over four years.

From year 4 on, income is projected to exceed cost by $40 000 p.a., and the negative income flows in the early years are recouped by year 7. Whilst this simple analysis ignores factors such as interest on borrowed money, taxation and inflation, it does illustrate that the economics of guayule production are likely to be favourable, especially when other credits are included.

The major benefit to Australia, however, could be the development of a renewable energy resource which replaced some requirements for crude oil imports (for oil refineries or petrochemical plants) or other products (such as natural or synthetic rubber) which would indirectly allow purchases of crude oil overseas without affecting the balance of payments. Australia currently imports each year over $40 million of natural rubber and $13 million of synthetic rubber. Local production of synthetic rubber from petroleum amounts to $36 million, and petroleum is also used to manufacture large quantities of other chemicals. This plant thus has the potential to reduce significantly Australia's imports of petroleum products. In addition, of course, many thousands of jobs would be created in agriculture, forestry and processing.

With Australian imports of 50 000 tonnes per annum of natural rubber, this requirement could be met by 20 plantations of a size similar to that used in the above exercise, namely 4 000 hectares. This would give a total requirement of 80 000 hectares.

Such plantations would also produce 25 000 tonnes of resins, equivalent to about 200 000 barrels of oil (or about 2.5 barrels/ hectare/year). Australia currently consumes about 250 million barrels of crude oil per year, and it is apparent that oil production based on local guayule rubber requirements would represent an insignificant contribution.

However, other species such as Euphorbia have shown already an ability to produce 20 barrels of oil per hectare per annum. Thus with improvements in yield and agricultural techniques, such plants could conceivably produce Australia's crude oil requirements on 5 to 8 million hectares.

Although this may seem excessive, it should be noted that in 1978 nearly 13 million hectares of land in Australia was used for growing wheat and barley. A study of land availability in Australia has indicated that about 25 million hectares of non-irrigated, arable land are available in Australia based on the suitability of rainfall, temperature, topography and soil type characteristics. As it is possible that Guayule and Euphorbia plants could be grown in areas with even less suitable characteristics than those used in the above study, it is unlikely that land availability should be a problem if their technical and economic feasibility can be established.

In view of the earlier suggestion that the bagasse remaining after the oil extraction could be converted to alcohol fuels, it is possible that the land requirements above could be reduced further. Assuming, for instance, that the bagasse was able to produce 20 percent of its weight as ethanol or methanol, that the bagasse is twice the weight of hydrocarbon oils, and that the alcohol fuels could be used as motor spirit replacements, then the total requirement of hydrocarbon plants could be reduced by one-quarter.

4. CONCLUSION

Up to the present time, there have been few if any instances in Australia of a general energy crisis, and generally there are ample supplies of most forms of energy including gas, electricity and coal. Increasingly, however, supplies of liquid fuels will become tighter as the producing countries deliberately reduce supply and as the physical capacity of producing regions decreases. Nevertheless, it is important to realize that petroleum supplies will not suddenly disappear, and it is therefore desirable that some caution be exercised when it is proposed that individuals produce their own fuels, regardless of cost.

In the shorter term, given the desirability of reducing consumption of petroleum fuels, the methanol or methyl fuel route appears particularly favourable in terms of raw material availability, available technology, performance in vehicles and economics.

Of the three main processes for producing liquid fuels by photosynthesis (viz alcohol fuels, pyrolysis oils and hydrocarbon plants) the latter option appears to be of most relevance to South Australia.

The main crops proposed for the production of ethanol are sugar cane, cassava, sugar beet, cereals and cellulose (wood or waste straw). Sugar cane and cassava have no potential in South Australia, and even for Australia the cost of developing the necessary plantations could be prohibitive. For example, to produce all of Australia's present gasoline requirements as ethanol would require about 2.5 million hectares of sugar cane (compared to the present 300 000 hectares) or 3 million hectares of cassava (none grown at present). Not only would the problem of finding such areas of quality agricultural land be immense (it is about 120 times the size of the Ord River development) but also the capital cost would be about $18 000 million with a cost of production estimated by CSR at 60 cents/litre (compared to 30 cents/litre now).

The availability of quality agricultural land for sugar beet or wood production is similarly in doubt, and certainly land is not available for grain production for conversion to alcohol (apart from tropical or sub-tropical crops such as maize, millet or grain sorghum). In brief, just to provide all of the motor spirit requirements from alcohol fuels (which accounts for only about half of the crude oil consumption in Australia) would require a large area of prime agricultural land, and certainly this is not feasible for South Australia or most of the other States.

In a similar manner, pyrolysis oils derived from waste products (straw, wood waste or domestic refuse) is limited by the availability of waste and its scattered distribution. Although some pyrolysis plants may be constructed, the contribution from them will be small.

In contrast, the hydrocarbon plants offer the possibility of utilising marginal agricultural lands not able to be used for other crops. On the basis of likely yields, an area of 5-8 million hectares of marginal land could produce all of Australia's current crude oil requirements. These plants could produce light hydrocarbons and diesel oils with the bagasse processed to alcohol fuels.

It is therefore important that agricultural research is initiated immediately to evaluate the performance of a number of species as hydrocarbon producers in our semi-arid areas. If successful, within ten years these plants could be supplying a significant part of Australia's energy requirements, at a time when world oil production is expected to start to decline. This is a challenge to agricultural research in this State but one I am confident you are well equipped to resolve.

Sector	Petroleum Products Use (%)
Transport	49
Industrial	26
Agricultural	7
Commercial	5
Domestic	3
Other	10

Petroleum Product	Petroleum Products Use (%)
Motor Spirit	46
Automotive diesel oil	19
Industrial diesel oil	13
Fuel oil	7
Heating oil, kerosene	5
Aviation fuels	4
Other	6

TABLE 1: South Australian Petroleum Product Use 1976-77.

Fuel	Petroleum Product Use (%)
Motor Spirit	45
Automotive Diesel Oil	54
Power Kerosene	1

TABLE 2: South Australian Agriculture Petroleum Product Use 1976-77.

Crude oil component	12.5
Product differential	4
Refinery costs	1
Supplier mark-up	1.5
Distribution costs	2
Retail margin	2
Excise	5
	28

TABLE 3: ESTIMATED COST BREAKDOWN OF MOTOR SPIRIT (cents/litre)

of Combustion igajoules/metric on)	Biomass constituents	Fuels from biomass	Fossil Fuels
50		Methane	Natural gas
45			
40	Turpentine	Butanol	Gasoline
35	Triglyceride oils ∼ steroids ∼ lignin		Fuel oil > bituminous coals
30		Acetone > ethanol	
25			
20		Furfural > methanol	
15	Wood > starch ∼ cellulose > sucrose > glucose		
10		Acetic acid	

TABLE 4: Comparison of Heats of Combustion of Selected Fuels

	COSTS ($per hectare)			
	First Yr. Crop	Second Yr. Crop	Third Yr. Crop	Fourth Yr. Crop
Seedlings	500	-	-	-
Cultivation	30	20	10	10
Planting Out	40	-	-	-
Field Care	50	50	50	50
Land Rent ($300 @ 10%)	30	30	30	30
Harvesting	-	-	-	50
Other Overheads	20	20	20	20
	670	120	110	160

TABLE 5: ESTIMATION OF AGRICULTURAL COST OF PRODUCTION

	First Yr. Field	Second Yr. Field	Third Yr. Field	Fourth Yr. Field	TOTAL
Year 1	670 000	30 000	30 000	30 000	760 000
Year 2	120 000	670 000	30 000	30 000	850 000
Year 3	110 000	120 000	670 000	30 000	930 000
Year 4	160 000	110 000	120 000	670 000	1 060 000
Year 5 onwards					1 060 000

TABLE 6: AGRICULTURAL COSTS OF PRODUCTION ($)
(1 000 ha per annum for 4 years)

Year	Agricultural Costs ($000)	Processing Costs ($000)	Depreciation ($000)	Total Costs ($000)	Income ($000)	Cash Fl ($000)
1	760	-	-	760	-	-760
2	850	-	-	850	-	-1610
3	930	-	-	930	-	-2540
4	1060	400	500	1960	2700	-1800
5	1060	400	500	1960	2700	-1060
6	1060	400	500	1960	2700	-320
7	1060	400	500	1960	2700	+420
8	1060	400	500	1960	2700	+1160
9	1060	400	500	1960	2700	+1190
10	1060	400	500	1960	2700	+2640
11	1060	400	500	1960	2700	+3380
12	1060	400	500	1960	2700	+4120
13	1060	400	500	1960	2700	+4860
14	1060	400	500	1960	2700	+5600
15	1060	400	500	1960	2700	+6340

Present Value of Costs @ 10% ROI = $15,582,000

Present Value of Income @ 10% ROI = $19,295,000

TABLE 7: Cash Flow Statement, Guayule Production

APPENDIX I : GUAYULE

a. History

Guayule (Parthenium argentatum Gray) is a native of the Northern Mexican desert and Big Bend National Park, Texas, U.S.A. It is a member of the daisy family and was familiar to the Aztecs who used it in making crude rubber balls.

Guayule has had an interesting and varied history. Early this century, wild guayule stands in Northern Mexico and Texas were harvested for rubber production and in 1910 guayule was the source of nearly 50% of all natural rubber consumed in the U.S.A. and 10% of the world consumption. Overuse of wild plants (71 million kilograms of guayule rubber were imported into the U.S.A. in 1912 alone) and failure to replant led to a virtual disappearance of the new industry's raw material source and mills were forced to close. The revolution in Mexico also helped to close down the industry.

In the late 1920's, Britain's control of Malaya and its resultant rubber monopoly suddenly increased rubber prices threefold. In Mexico and California guayule rubber became profitable again and production resumed. Major Dwight D. Eisenhower, assigned to study guayule in connection with national security, recommended further development of the industry but the depression of the thirties postponed the project until its short-lived resurrection in 1942. When rubber supplies from South East Asia were cut off during World War Two, the U.S.A. spent $30 million on the successful Emergency Rubber Project to develop guayule as a domestic source of rubber again. The crop was grown on high quality farmland in California and after the war the farmers wanted their land returned. With the renewed availability of cheap rubber from Asia and the new availability of completely synthetic polyisoprene rubber, the government withdrew its funding and ordered the 11 000 hectares of guayule to be burnt.

At the request of the Council for Scientific and Industrial Research, investigations commenced in July 1942 at the Waite Agricultural Research Institute to assess the feasibility of producing rubber from guayule in South Australia. Because of the close co-operation with the US research, the local investigations were not continued after the cessation of war. Because of the limited amount of time, labour and funds during the war, very few conclusive results were obtained although considerable progress was made on germination techniques and identification of the best soil and climate conditions. At that time, using the "Canberra" strain (now considered inferior) the best non-irrigated yields of rubber were 1 200 kg/ha.

Various small scale plantings have taken place in Western Australia in 1929, 1943 and 1959. More recently, in 1977, the CSIRO started small trials in Western New South Wales to determine the appropriate soil and climatic conditions for guayule.

Several countries around the world (e.g. U.S.A. in Arizona and California, Israel) are now conducting research programmes involving guayule. Both the Firestone Tyre and Rubber Company and Goodyear have commenced trial plantings of guayule and Mexico has a pilot production plant. It plans to process 3 million tonnes of wild guayule shrubs growing on 4 million hectares - harvesting 350 000 tonnes of shrub, yielding 35 000 tonnes of rubber annually.

b. Reasons for Renewed Interest

The U.S. National Academy of Sciences 1977 report listed the following reasons for initiating research into guayule. Indeed, the report specifically nominated South Australia as one location at which trials should be undertaken.

(i) The prices of both natural and synthetic rubber are increasing and seem likely to climb much higher. It has been estimated that the price may double by 1980. The increase in demand for natural rubber due to population increase and changes in technology is not likely to be matched by any increase in *Hevea* production. It is believed the rubber tree has reached the limit for genetic improvement of yield after a ten-fold improvement since the Second World War. The Malaysian Rubber Research and Development Board concluded that the demand for natural rubber will outstrip supply by 1 million tonnes in 1980 and by 2 million tonnes in 1985. Prices were expected to reach $1.10 per kg in 1980. An indication of import prices (fob not market price) in Australia in recent years can be seen below:

Natural Rubber Australian Import Prices (fob)

1971-2	30 cents/kg
1972-3	34 cents/kg
1973-4	52 cents/kg
1974-5	44 cents/kg
1975-6	52 cents/kg
1976-7	71 cents/kg
1977-8	78 cents/kg
1978-9	96 cents/kg
8-1	1.10 cents/kg

(ii) Although synthetic rubber is cheaper, natural rubber is essential to industry. Its elasticity, resilience, tackiness and resistance to heat are unmatched by any synthetic rubbers now available. Conventional automobile tyres, for example, contain about twenty percent natural rubber and radial tyres which now dominate the market contain as much as forty percent, as do truck and bus tyres. Large tyres on aircraft, tractors and earthmoving vehicles are made almost entirely of natural rubber. Guayule rubber could serve for all these uses because its chemical and physical properties are virtually identical to those of Hevea rubber. No chemical difference between the two have been detected in several studies, even with sensitive techniques that can demonstrate as little as 0.5% of structural difference.

(iii) The long range outlook for cheap petroleum derivatives for the production of synthetic rubber is hardly favourable considering the increase in oil prices. Natural rubber would also seem desirable in that it is a renewable resource whereas oil cannot be replenished.

(iv) South East Asia is very unsettled politically. Over 85 percent of the world production of natural rubber comes from Malaysia, Indonesia, Thailand and Sri Lanka.

Liberia, Nigeria, Zaire and India are the major remaining sources of supply. It could be in the interests of national security for Australia and America to produce their own rubber. Domestic production is desirable from market control and balance of payments points of view.

(v) New technologies for cultivation and processing and the existence of weedicides, now ensure that problems encountered in the earlier production work are no longer relevant.

c. The Plant*

Guayule is a bushy, perennial shrub up to about 1 metre high. It is long-lived and hardy, with a life expectancy of 30 to 40 years under arid conditions.

The plant possesses a taproot which may penetrate the soil up to 6 metres in depth. An extensive fibrous root system may spread to 3 metres laterally. The well-developed root system accounts partly for its drought resistance. In severe droughts, guayule may become dormant. Leaf fall often occurs with the onset of drought. One of the main advantages of guayule is it can remain in the field without losing its rubber, and thus can be left in the field during a drought without loss of the plant or its product.

In the guayule plant about two-thirds of the rubber is in the stems and one-third in the roots. There is no extractable rubber in the leaves. Rubber comprises approximately 10% of the dry weight of native guayule plants. However, there is considerable genetic variability. Selected strains that were cultivated prior to World War II had approximately 20% rubber after 4 years growth, and further improvements have been reported since, with yields up to 26 percent.

When guayule grows actively it produces little or no rubber. If the plant is stressed, growth slows down and products from photosynthesis are diverted into rubber production. The main stress factors involved are low temperatures and decreasing moisture. The rubber produced by the plant is not used by it.

*From the report on Guayule by the Western Lands Commission of N.S.W., 1977.

Resins constitute 10-15% of the plant (dry weight). These resins includes terpenes, sesquiterfenes, diterpenes, glycerides and low molecular weight polyisoprene hydrocarbons.

(i) Reproduction

Pollination is by wind and insects. Guayule is a prolific seed producer - seed is set throughout summer and autumn. Under cultivation, harvests of seed of 300 kg per hectare were common and collections as high as 1100 kg were recorded. By the end of the first year, abundant seed is produced in plantations.

(ii) Propagation

Guayule is normally propagated by nursery grown seedlings, although grafts and cuttings can be successful.

If stored properly, seeds will remain viable for several decades. Young seeds require simple treatment to break the dormancy.

Exposed ends of broken roots may give rise to adventitious shoots if moisture is available.

(iii) Breeding

Guayule belongs to a genus with 16 species and it can be crossed with all of them. Guayule can cross normally as well as apomictically (i.e. without the union of male and female elements). The latter can be used to produce off-spring identical to the parent plant. There is also the possibility of crossing guayule with other Parthenium species.

In research conducted in the U.S.A. in the 1940's, plant breeding showed great promise for improvement of guayule rubber production.

(iv) Soil

Guayule grows naturally on soils of moderate to high fertility which are calcareous or have a neutral reaction. In Mexico, the densest stands of guayule are on limestone soils. The latter may be similar to the mallee saltbush soils of

South Australia and south-western New South Wales.

Characteristics of soils most likely to be suitable for the cultivation of guayule are:

Texture - A light to medium texture is preferable. A sandy loam texture is the most suitable.

Structure - The structure should be loose, permeable and friable. Good consistence and tilth are very desirable. The soil should be relatively free from stone and gravel.

Moisture - Good moisture holding capacity is essential.

Drainage - The drainage should be good throughout the profile.

(v) Climate

Guayule can produce rubber in the very dry climates of its natural habitat (a sub-tropical temperate climate with low or erratic rainfall). However, it is not yet clear if it can be cultivated economically in regions as arid as its native habitat. Under dry land conditions where droughts are common, guayule is hard to establish and may take longer than 7 years to develop commercially useful quantities of rubber.

C.S.I.R.O. investigations showed that the most suitable area for guayule would have an average rainfall of 350 mm. The climate would be a wet-dry one; most rainfall would occur in the winter-spring period with little or none in the summer. Guayule needs to be free from very high or very low temperatures.

(vi) Rainfall

In the natural habitat of guayule in the U.S.A., rainfall varies from 250 to 500 mm per year with a summer dominant characteristic.

Work from the U.S. Emergency Rubber Project during World War II showed that 280 to 640 mm of rainfall annually were needed for commercial production. On a long rotation (4 to 8 years) 410 to 460 mm of rainfall annually were sufficient. Other research has shown that dryland guayule cannot be grown successfully with less than 375 mm of rainfall per year and overall the range of 375 to 500 mm of rainfall annually appeared to produce the best rubber yielding guayule in the U.S.A.

In conditions of extreme drought, it may require from 4 to 7 years for guayule to reach a commercially exploitable size.

Guayule can survive arid conditions, but if the annual rainfall is less than 350 mm, supplemental irrigation may be needed to give worthwhile yields in a reasonable period. However, it has been found that whilst plant growth is greater under high precipitation or irrigation, the percentage of rubber falls and the rubber yield per hectare is not much different.

Under dryland cultivation it is desirable to have supply of moisture at the beginning and during the first half of the growing season (spring-summer) and also to have a dry period of at least 2 months duration before the cold season commences.

(vii) Temperature

The characteristics of the climate where guayule grows in the U.S.A. are winter (mean) 10°C; summer (mean) 17°C; maximum 43°C and minimum -8°C. Guayule does not occur where mean air temperatures are above 21°C. There is a 250 day growing season.

The Waite Institute's research on guayule in South Australia has shown that, with sufficient moisture, there is active growth above 15°C, no new growth at less than 10°C and plants are not affected by frosts at temperatures above -13°C.

Overseas research has shown that the best growth of guayule occurs at 32-38°C. This research concluded that the mean temperature should be above 13°C and that below 16°C mean temperature, growth rate is slow and plant mortality high.

The general variations of temperature during the growing season have little effect on the growth rate of guayule. Hot days and cool nights favour rubber production.

Wild guayule can survive temperatures below 0°C. Cultivated guayule, especially when it is young is frost sensitive. However, if plants are hardened off by gradually decreasing temperatures or reduced available moisture, they can withstand temperatures below -7°C.

d. Agricultural Techniques

There is great deal of information on certain aspects of guayule production, but other aspects still require investigation.

Guayule seed consists of an embryo and some attached parts which tend to inhibit germination. There may also be some inherent dormancy, but this can be overcome by treatment with hypochlorite. While treated seeds germinate readily, it has been found that they have low emergence energy and hence are unable to compete with weeds. Nursery production of seedlings is therefore desirable.

(i) Nurseries

Treated seed is sown with superphosphate on a level, light textured soil in the seed bed in November-December, and covered to about 0.6 cm depth. Watering is necessary during germination and up to transplanting. Approximately 2.5 million useable seedlings can be produced per hectare of nursery space, sufficient to plant about 15 hectares.

(ii) Transplanting

Seedlings are transplanted at 4 to 9 months, but can be held up to 2 years in nursery beds. Prior to transplanting, the plants should be hardened by cool temperatures or low soil moisture. The seedlings are cut to a height of 5 cm and the roots trimmed at 15 cm. Although transplanting can occur at any time of year, best results are obtained when minimum temperatures were above 10°C and maximum temperatures below 35°C.

Land preparation involves ploughing to 15-25 cm depth using conventional tillage equipment for all land preparation operations. Planting is done with a machine planter at spacings 70 x 60 cm.

(iii) Crop Production

Weed control is essential, especially in the first two seasons. This can be either mechanical (when the plants are small) or by herbicides. Several cultivations may be necessary in each of the first few years to control weeds and maintain soil condition.

Fertilizer application does not appear necessary since guayule is not a serious soil depleting plant. Although irrigation may be desirable in certain conditions, it does not appear to increase markedly the yield of rubber.

Guayule is resistant to the root-knot nematode, but susceptible to other diseases such as wilt, root rot and dieback. Guayule can be damaged by insects such as grasshoppers, particularly in its seedling stage.

e. Harvesting

Under dryland cultivation, harvesting might take place every 4 or 5 years. With irrigation, this could be reduced to 2 or 3 years, but at the expense of rubber yield.

Guayule is harvested as a whole plant (including roots) with a digger-harvester such as a modified sugar-beet harvester. The plant is then windrowed and baled for transport to the processing plant. Alternatively, a forage harvester could be used.

Some research has examined the possibility of coppicing, which would allow at least two crops from the same plant in a shorter period of time. Other research has examined the possibility of harvesting one year old plants after direct seeding in the field: this reportedly produced nearly 1200 kg/ha/year.

f. Extraction

In contrast to Hevea and other Euphorbia plants, in which rubber is found in the form of a latex in connected channels which run vertically down the parenchyma, in guayule the latex is found in small particles in isolated, thin-walled cells with no possibility of flowing. Guayule also produces up to 15 percent of resin which is found in the channels along the stalks. A typical composition of harvested guayule is as follows:-

	Range	Likely Proportion*
Moisture	45-60%	
Rubber*	8-26%	20%
Resin*	5-15%	10%
Bagasse*	50-55%	50%
Leaves*	15-20%	20%
Cork*	1-3%	
Water Solubles	10-12%	

*Dry Weight Basis

Because the latex is found in isolated cells from which rubber must be extracted physically or chemically, this requires a thorough extraction of fibres from the shrub to permit the recovery of the greatest possible amount of rubber. Furthermore, the rubber must be purified and standardised in order to attain high standards of quality.

After numerous experiments on the laboratory level, in April 1976 a pilot plant was designed and built in Mexico for the testing of a new guayule industrialisation process. The central objective of this process is total utilisation of the shrub as shown in the block diagram in Figure 1. In this manner, recovery of the diverse by-products will allow an increase in the economic yield.

The shrubs are first dipped in hot water for 10 minutes at 75°C. This coagulates the rubber and removes foreign material and leaves, which contain no rubber but do contain copper, manganese and resinous compounds that contaminate the rubber. The plants are then passed through a hammer mill and a Bauer mill (a device used in paper making) which break open the rubber filled cells. The pulping is done in water with caustic soda added. The material is transferred to a slurry tank where the water-logged bagasse sinks, the rubber worms float and are skimmed from the surface. They are then run through a second tank where they are rinsed and then treated with a detergent. Guayule worms contain 17 to 25 percent resins which are removed with acetone. The acetone is then distilled and recycled. During this process the rubber may be treated to modify the product.

g. Products

Along with each tonne of purified rubber, guayule produces about two tonnes of bagasse, one tonne of leaves and half a tonne of extracted resins.

The resins could be treated in a simple distillation column to recover volatile hydrocarbons of important commercial value. The remaining resins could be processed to recover adhesives, drying oils, rubber additives and other chemicals, but it is more likely that the oil would be used as a fuel (particularly diesel).

Guayule leaves are covered by a hard, cuticle wax with a melting point of 76°C which is one of the highest ever recorded for a natural wax, making it competitive with carnauba wax.

The bagasse can be used to produce paper pulp or for conversion to alcohol fuels. Alternatively, it might be used to supply the energy required in the process by direct burning, as with sugar cane production.

The seeds could be used for oil production or possibly animal feed after requirements for seedling production are met. As there are over 1 million seeds per kilogram and seed yields of at least 300 kilogram per hectare are expected, significant quantities of seed could be available.

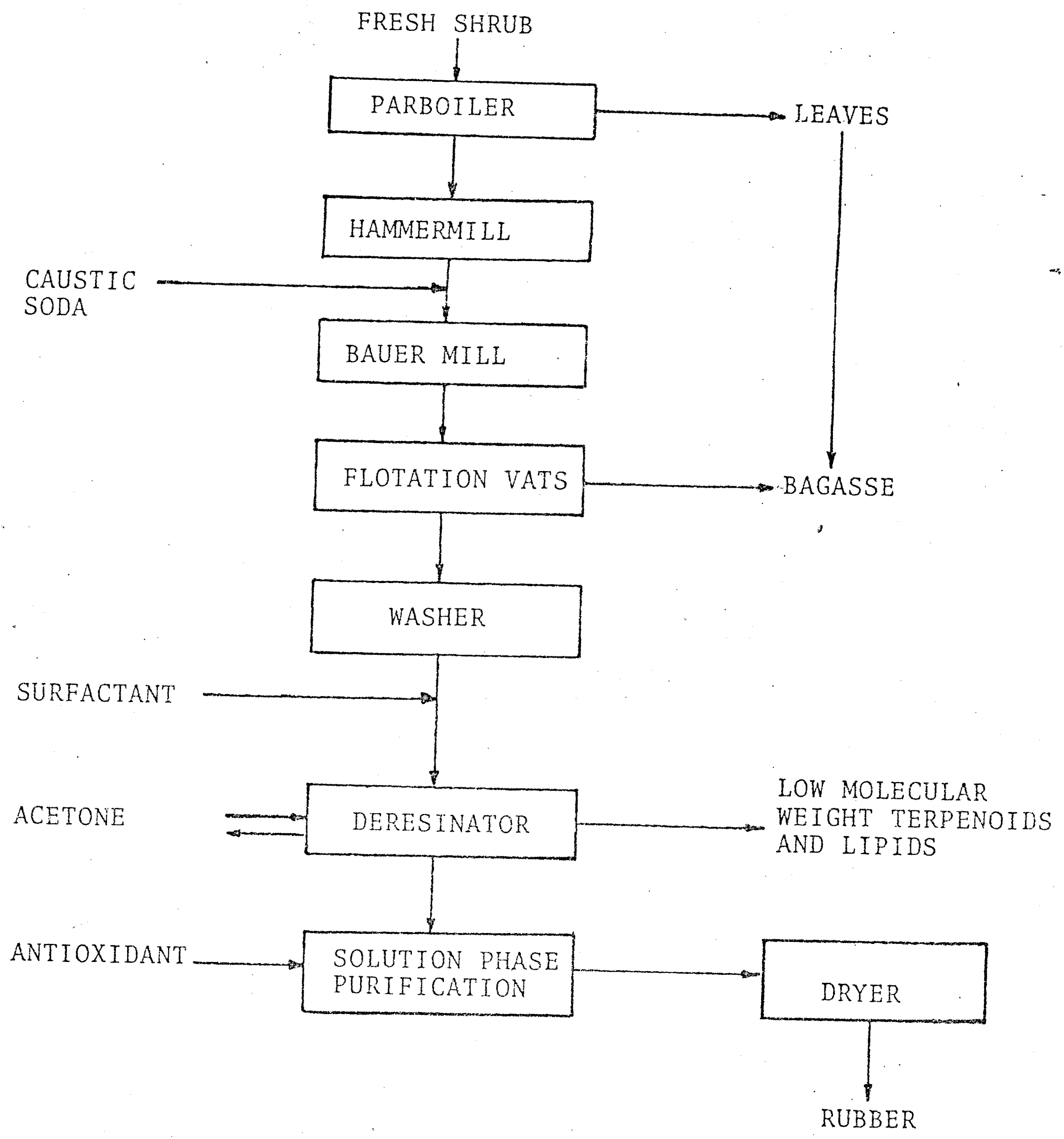

FIGURE 1: Mexican Process for Guayule Rubber Extraction

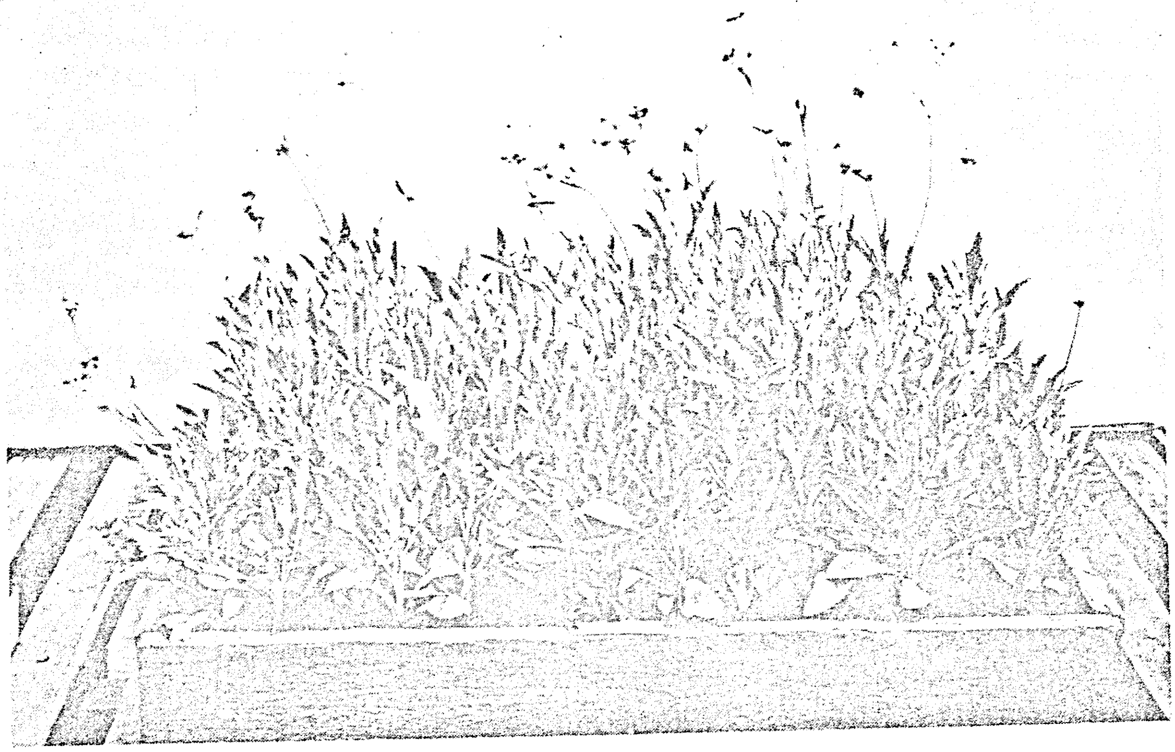

Fig. 2 (1) November, 1942. Seed box of guayule 18/11/42. Guayule sown 14/8/42.

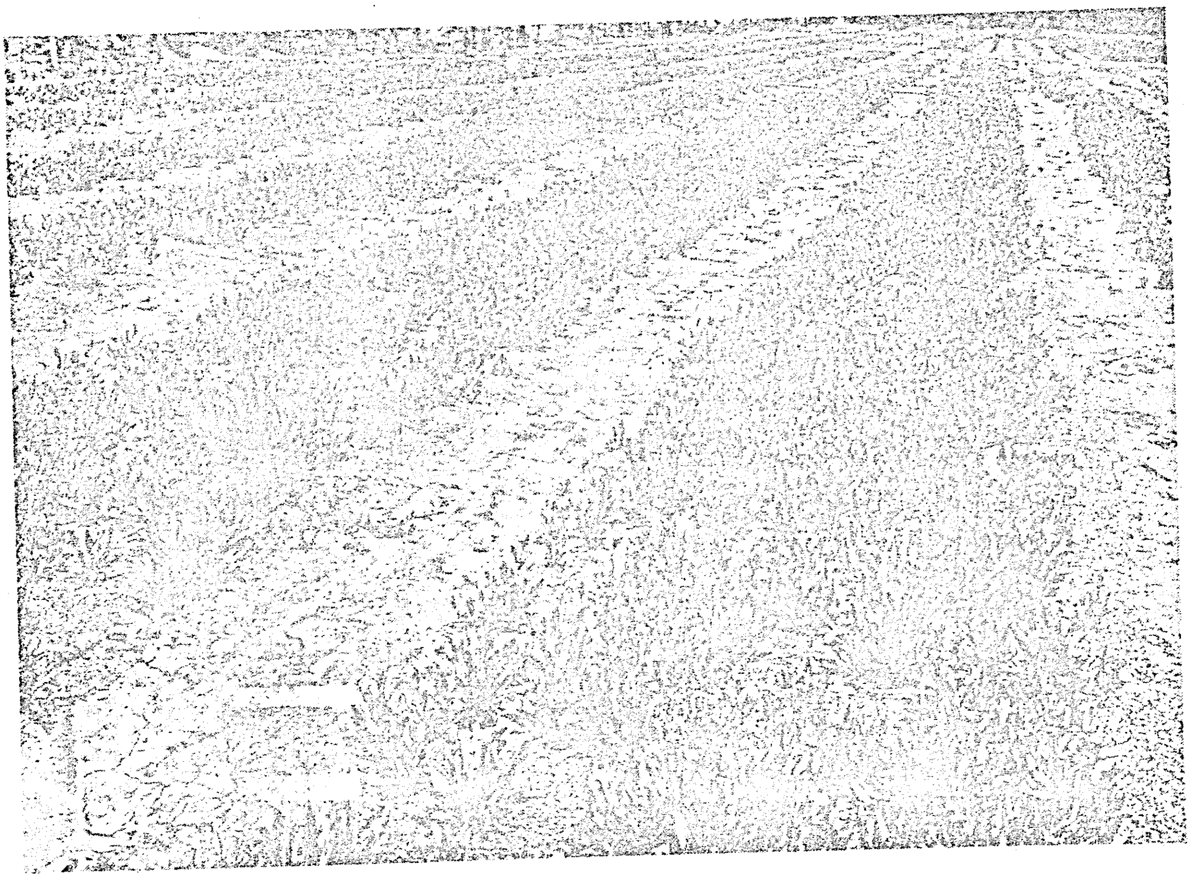

Fig. 2 (2) January 25, 1943. Development of seedlings, Kemps nurseries. Second planting.

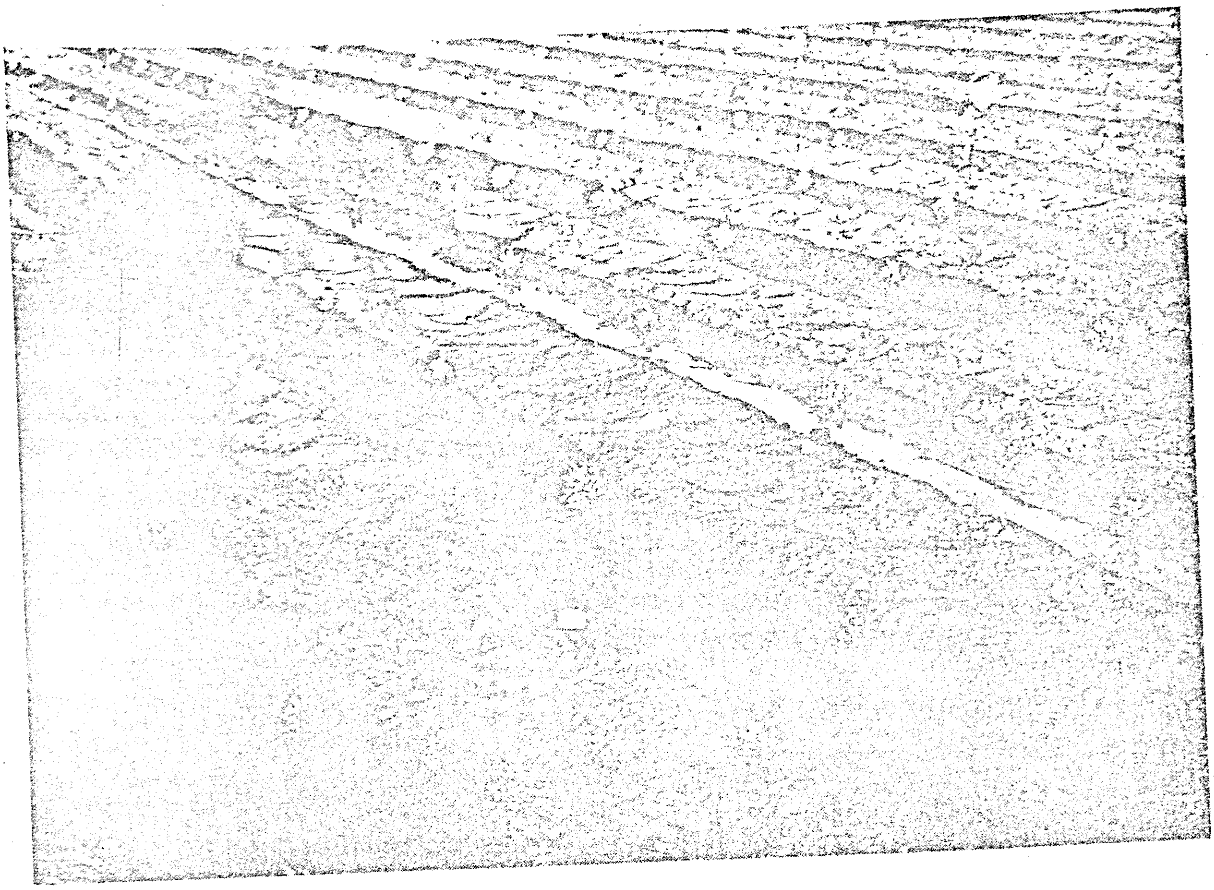

Fig. 2 (3) 3/6/43. Seedlings at Loveday on 3rd June, 2 months after planting.

Fig. 2 (4) 11/5/45. No. 9 camp. Guayule planted by machine October 1944. Photographed against light. Plants planted for only 7 months.

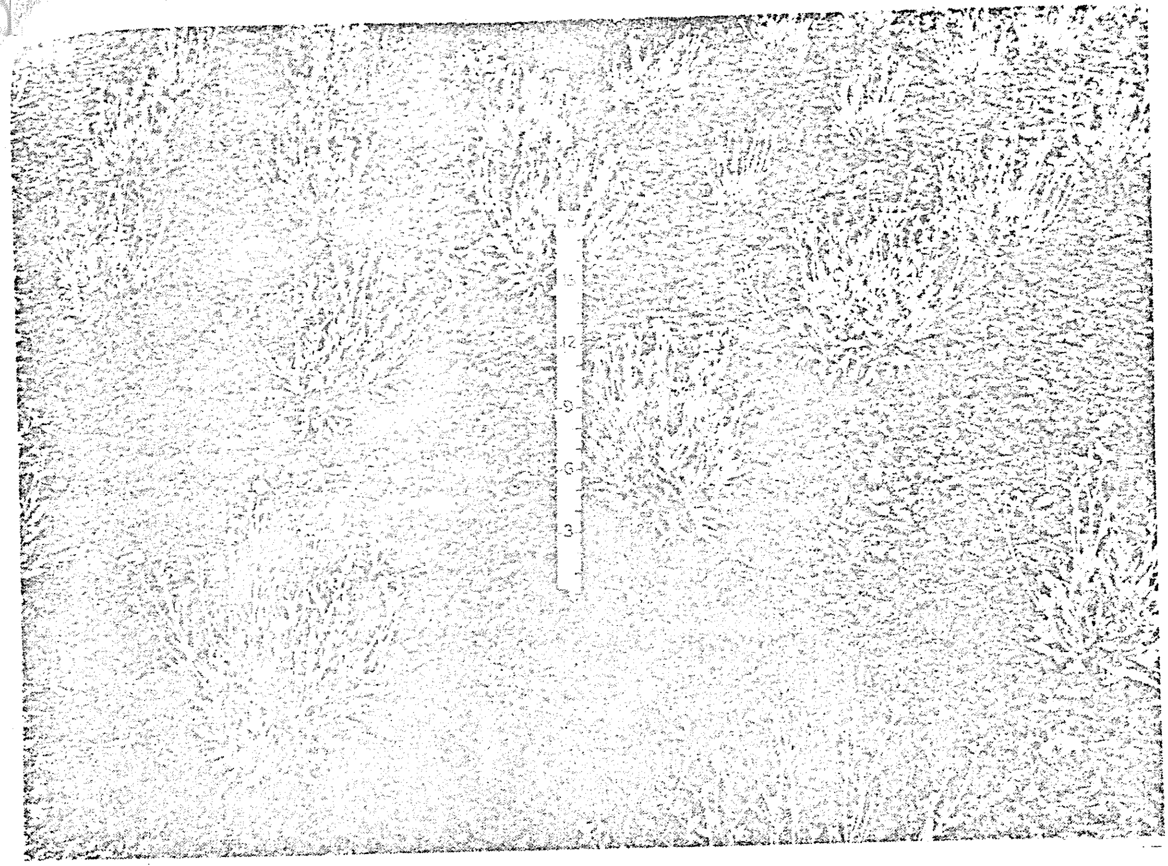

Fig. 2 (5) March, 1943. Intermediate view of plants at Morphett Vale.

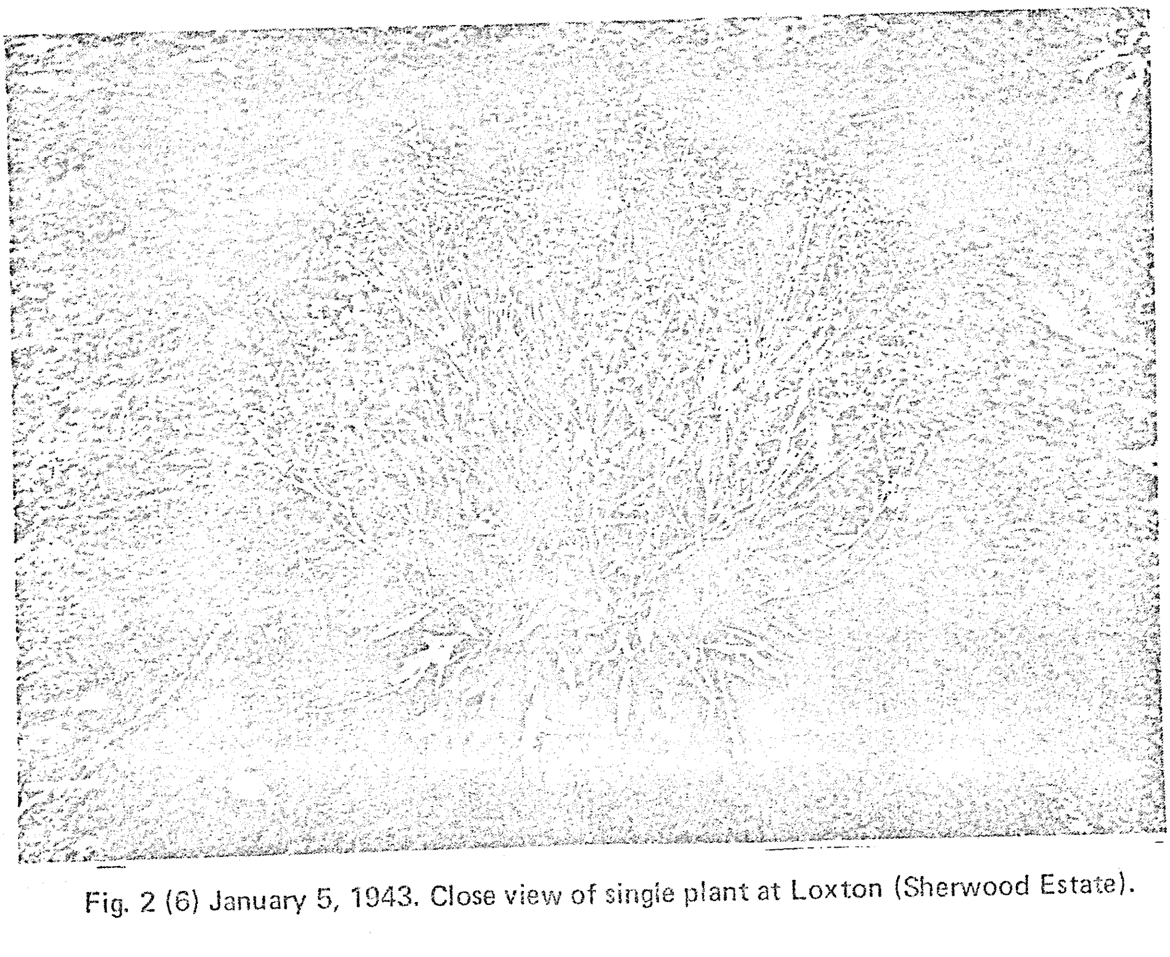

Fig. 2 (6) January 5, 1943. Close view of single plant at Loxton (Sherwood Estate).

Photographs courtesy R. Balk, Waite Institute Photographer.

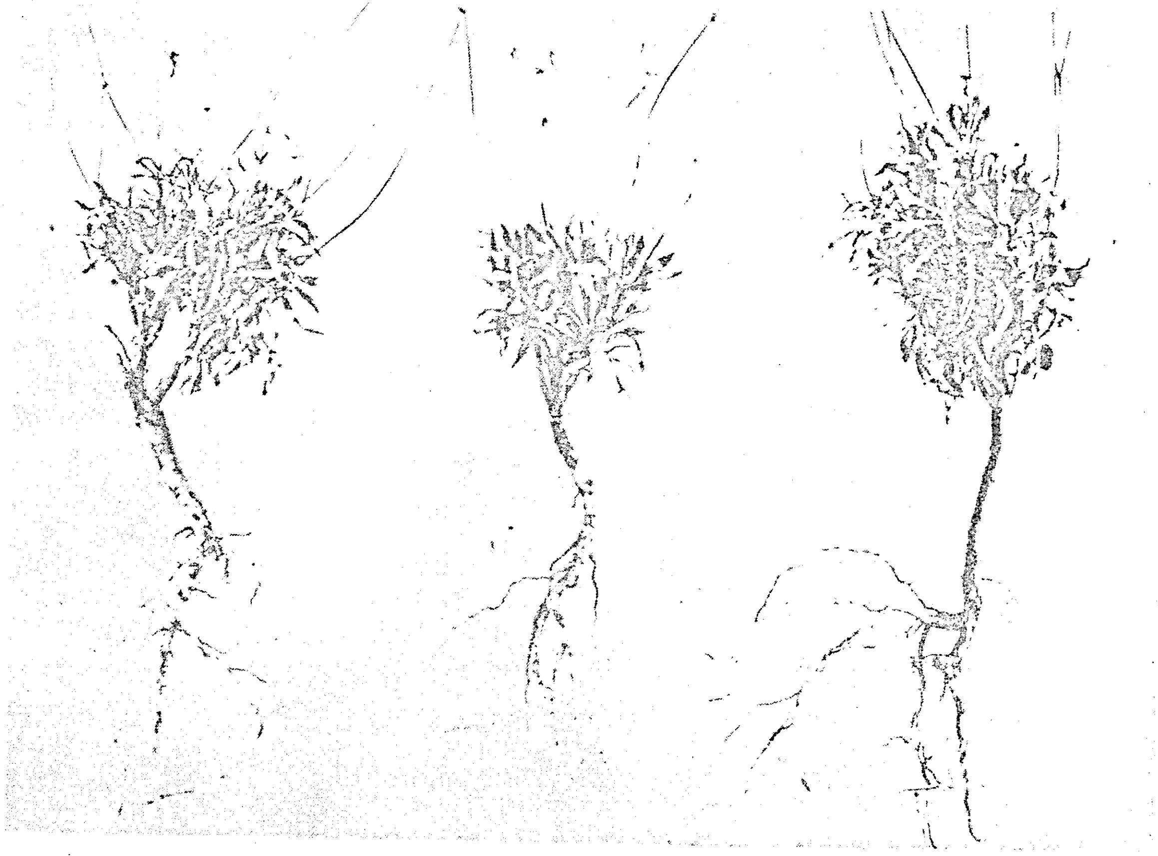

Fig. 2 (7) May 19, 1943. Guayule plants from Morphett Vale, October 1944.

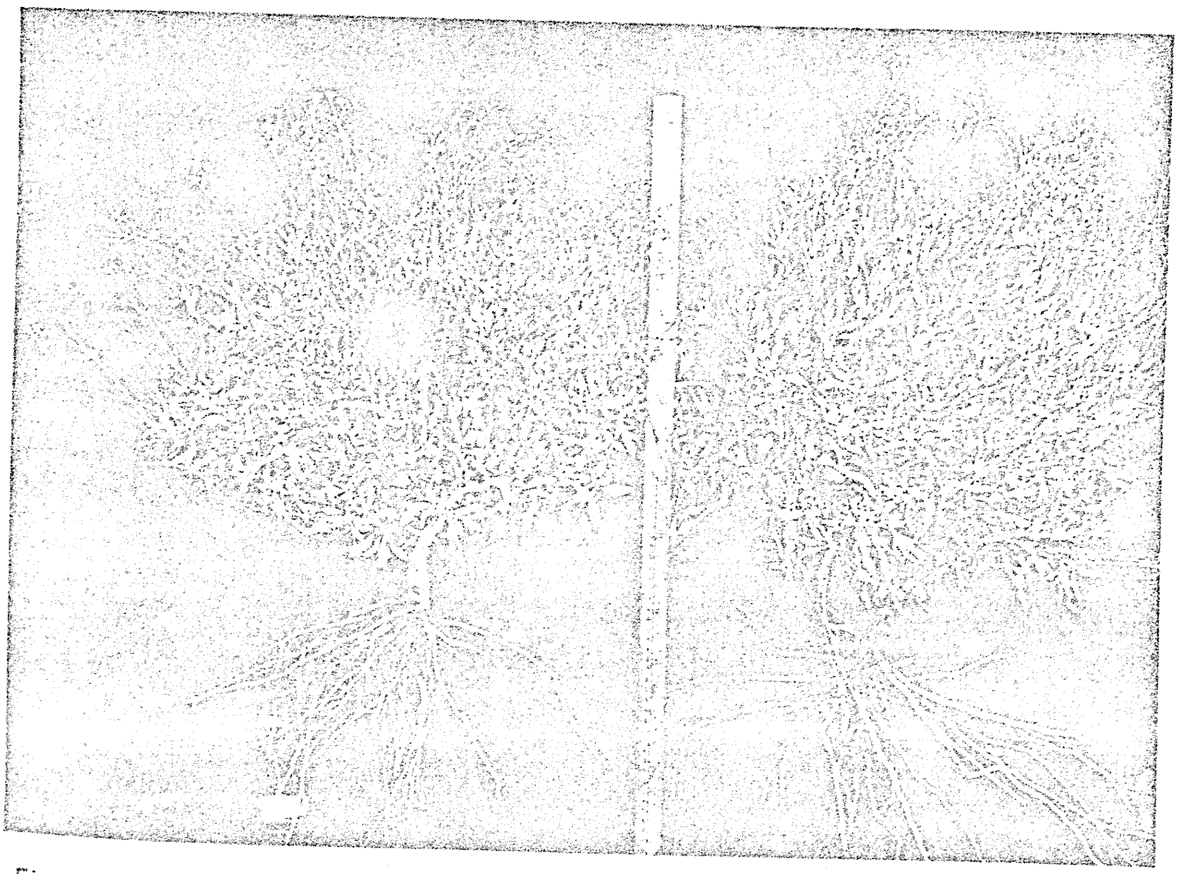

Fig. 2 (8) 7/6/43. Specimen plants pulled at Berri 3/6/43. Seedlings planted in October 1942 and irrigated four times from on Berri sand.