OALS REPORT

AN INTEGRATED APPROACH TO GUAYULE RESEARCH

By William G. McGinnies &
Jonathan G. Taylor

April 1979

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Development of guayule, Parthenium argentatum, as a dependable source of domestic rubber is complicated by the palnt's anatomical, physiological, and genetic complexity, especially when cultivated under conditions not native to it. Domestication of the guayule plant involves several problems, among them genetic manipulation and breeding, the expense of guayule stand establishment, and the effects of irrigation on its rubber-producing capacity. In addition, economically feasible rubber production depends on the assessment of economic, environmental, institutional, and socioeconomic factors. Because of the intricate nature of the research needed to solve these problems, the authors of this paper call for an interdisciplinary, integrated approach to the study of all aspects of guayule rubber production and provide a structure for this approach.

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INTRODUCTION

Guayule *(Parthenium argentatum)* is a complex plant that requires an appreciation of its growth and rubber-producing capacities if its full potential as a source of domestic rubber is to be achieved. Guayule is not a fully domesticated plant. The various existing strains and varieties are little more than once removed from the native population, hence guayule culture under various conditions unlike those of its native habitat warrants careful and extensive study.

Since growth and rubber production within the plant have an independent or even antagonistic role as related to cultural practices, guayule production involves many problems not common to most domestic crops. Solving these problems is complicated by the paucity of knowledge about how the plant converts simple carbohydrates to complex hydrocarbons.

Guayule is unique in many ways. It is the only species within the 16-specie *Parthenium* genus that produces significant amounts of rubber, yet it crosses freely and sometimes naturally with other *Parthenium* species. Unlike many hydrocarbon-producing plants it has no latex canals. The rubber is confined within plant cells and can be obtained only by disrupting the cell walls which involves using special harvesting and processing equipment and techniques.

The National Academy of Sciences stated in its report, "Guayule, An Alternative Source of Natural Rubber," that higher rubber producing

strains would have to be developed before guayule could become a commercial crop. It may be nearer the truth, however, to say that guayule will not become a commercial crop until cultural practices are developed to obtain the full benefit of genetic potentials. Arbitrarily establishing a rubber percentage floor as a basis for economic production is not realistic. With high concentrations of shrubs per acre and low production costs, a lower rubber percentage might be sufficient to support a profitable enterprise.

Guayule strains with a potential of producing 20 percent rubber by weight have been available since the beginning of World War II, but this yield has never been closely approached in short term field production. Collections from Mexico have assayed as high as 20 percent rubber by weight but it must be remembered that these yields were obtained from plants more than ten years old. The highest rubber percentages obtained by the Intercontinental Rubber Company were from dry-land shrubs 7 to 10 years old which produced 18 percent rubber at the extraction mill.

It is known that rubber percentage increases with age but it is not known whether maximum percentages can be attained by either cultural means or chemical treatment of 2-5-year-old shrubs. No breeding work has been done to induce early maturity and the effects of genetic manipulations versus cultural practices are largely unknown with respect to increasing field yields.

Plant modification by genetic manipulation and breeding will be one of the major elements in producing rubber from guayule economically. However, while increasing inherent capabilities of guayule to produce rubber

and to overcome various hazards and problems of reproduction, field production and processing is very important, enhancing these capabilities constitutes only one set of factors that will produce success or failure. Under production, the guayule plant must be able to tolerate a range of temperature, moisture, soil and other conditions as well as respond to manipulation of controllable influences. It is the sum total of all these interactions that determines the end product, neither the hereditary characteristics nor the environmental conditions alone can be considered to be the guiding forces.

Acknowledging the effects on guayule rubber production of these interactions leads to a strong argument for conducting integrated studies of all aspects of guayule production. To conduct studies sequentially and one at a time or in isolation may well materially impede research and foster inefficiency because findings that could be obtained through full field trials would remain in doubt.

Guayule shows some plasticity in that it has been grown successfully on granitic soils under winter precipitation whereas in its native habitat it is limited to limestone soils under a basically summer precipitation regime. However, there is evidence that some apparent plasticity is due to individual plant variations that allow growth in other than native soils and climates.

Guayule genetic characteristics are both advantageous and disadvantageous with respect to domestication. The basic 2n chromosome number is 36, but forms 54, 72 and 108 chromosomes occur in natural populations and a 144-chromosome form has been reported by plant breeders. Most cultivated

guayule strains have been the 72-chromosome form, the same number characteristic of mariola, but plant breeders have worked with all forms which has led to variations in plant cultivars that may complicate commercial development programs. Interspecific crosses have complicated the situation further because each new strain has different requirements and reactions ranging from seed germination to quality and quantity of rubber produced.

Because of these variations and because of the varied reactions to environmental, cultural and processing manipulations under field conditions, it is essential to conduct operational activities simultaneously with breeding studies. Coordinating operational and breeding studies creates the need for establishing large-scale test plantings as soon as possible.

Plantations large enough to stimulate commercial growing conditions are needed to test variations in soils, irrigation, weed control, and harvesting and to determine the amount, quality and availability of rubber produced. Pending pilot-plant construction the amount, quality and availability of rubber can be determined approximately by using bench-model-scale laboratory extraction to simulate processing plant operations.

Guayule plant breeding cannot focus on rubber content alone or on disease resistance or on any other single element related to cultivation; it must be founded in the entire production cycle from seed to marketable rubber. The seed must have good germination capability and the seedlings must be able to survive in competition with weeds under field conditions. The plants must have good growth characteristics and economic rubber yields under one of several age options, and the crop must meet harvesting and storage requirements. Finally, both shrub and rubber characteristics must be such as to allow milling of commercially acceptable product rubber.

Perhaps the most difficult problem to solve is establishing stands of guayule appropriate for field production. On the one hand are the difficulties of developing planting techniques to establish plants in the field and on the other hand are problems associated with controlling plant numbers and distribution to provide a uniform spacing and density to ensure maximum rubber production.

Guayule stand establishment has constituted the greatest single expense in guayule production. Nursery production and seedling transplanting are relatively expensive operations compared with direct seeding, and greenhouse production has been even more costly. The ideal method to establish stands seems to be direct seeding, which as yet has not been accomplished satisfactorily. Problems of seed germination under field conditions and of weed competition with seedlings that do germinate thus far have discouraged the use of direct seeding in the field. Recent developments in coating seeds may help solve germination problems and obtaining uniform stands of the desired density, but weed competition problems remain.

Irrigated guayule presented a complicated management problem during the World War II Emergency Rubber Project (ERP). There were many difficulties which at times appeared to be contradictory. An abundant moisture supply in a high-temperature and good-soil growing environment such as the San Joaquin Valley plantations in California produced 10 tons of luxuriant shrubs per acre in two years, but the shrubs contained only a small percentage of rubber. When shrubs were produced under these conditions, the rubber also was distributed mainly in the woody mass of the plant rather than in the cortex, which caused recovery problems using the

conventional pebble-milling process. Under optimum conditions which allow guayule to grow at an uninterrupted luxuriant rate, little or no rubber will be deposited, whereas low temperatures, or, in warmer areas, induced drought (withholding irrigation) modify metabolic and physiological activity to increase rubber accumulation.

GUAYULE MASTER PLAN

Guayule development and production is a far-ranging undertaking which demands involvement of a multiplicity of disciplines. The points of involvement of each discipline are not restricted to a specific research target in the overall research structure. The research of the economist, for example, should include studies of competition economics, production economics, processing economics, and economic impacts of guayule development. The objectives of the plant breeder must be coordinated with those of the analytical chemist, the economist, the processing engineer, and the microbiologist. It becomes obvious that research as broad as guayule development, production and processing cannot be considered to be addressed by any single discipline, nor even by a loose structure of related disciplines; guayule research must be interdisciplinary, integrated and holistic if development and production are to be achieved.

THE DIAGRAM

The accompanying flow diagram (see insert) represents an overall research structure designed to culminate in successfully developing and cultivating the rubber-producing plant guayule (*Parthenium argentatum*).

The diagram was developed using "structured programming," a systems engineering organizational methodology. Structured programming is a "top down" organizational system in which the diagram begins with the most general question or problem to be addressed, breaks out the second-level components (that aggregate of questions which, if answered, would answer the level-one general question), breaks the second-level questions into the broadest component questions, and continues breaking questions until the level of specific detail sought is attained. "Information systems" are treated separately since information exchange, collection and dissemination are dependent upon whole-system operation or completion.

The diagram does not specify research priorities according to flow position; it simply imposes an overall integrative structure upon guayule research as it is now constituted. Using this holistic approach should demonstrate the interrelationships between various aspects of guayule research and identify research gaps.

The interdependence of the system components cannot be overemphasized. Economic analysis, for example, that does not draw its basic information from the plant, growing conditions, production, product and impact assessment studies will not supply the economic information necessary to produce guayule successfully. In turn, the findings of the economic researchers must be part of the decision criteria of the chemical analyst, the agronomist, and the plant breeder. Information generated at level three in the diagram will satisfy the information needs of level two, but only if all level-three research activities are fully integrated and exchanged. While

individual categories on the chart may be segregated for convenience of handling, the final impact of any one item must be determined in a universe where all may influence and be influenced by each individual item.

The Plant

In the diagram, first consideration is given to the plant and its anatomy, physiology and genetics. The plant category combined with the growing conditions category and its subcategories of climate, soils, water and biological constraints forms the basis for the production processes that relate directly to the products, economics and impacts diagram categories, all of which emphasizes the need to recognize interrelationships in all guayule research and development activities.

The plant has characteristics that determine its culture requirements and its capability to produce rubber. Various plant processes determine growth rate and rubber production and are amenable to some manipulation within limits set by genetic controls; all need to be considered relative to each other.

Growing Conditions

The native environment of guayule gives an indication of its climate and soil tolerance. Culture has shown, however, that some climate and soil variations may not only be tolerated but in some instances, such as carefully controlled irrigation, actually increase both plant growth and rubber production. The biological restraints, including diseases, insects and consumers of various kinds, must be considered relative to the plant and its environment.

Production

The production category embraces the various aspects of propagation, growing, harvesting and processing, each of which is discussed separately.

Propagation

It is logical to start with propagation under the production category. Reproduction options are shown on the diagram with the principal problems indicated. Evaluating the options and the specific contribution each may make is the first task to be undertaken. Cuttings and tissue culture, for example, appear to be rated low for field program uses, but may be rated high for genetic and physiological study uses. Establishing guayule in the field is the greatest production expense and may be the determining factor in producing guayule rubber economically. Greenhouse and nursery establishment would seem to have lower research priorities than direct seeding. Growing and transplanting greenhouse and nursery seedlings, however, should be considered because direct seeding has not been proven to be a successful field production practice. Economic analyses must be an integral part of alternative propagation studies, for unless establishment costs can be minimized, successful commercialization of guayule would be doubtful.

Direct seeding may have the most appeal of the propagation options, but it has offered only false hope thus far. Establishing a good guayule stand in terms of number, distribution, survival in competition with weeds, and meeting moisture requirements for germination and growth are all problems to be overcome. The major problems associated with establishing guayule

by direct seeding under irrigation may be solved, but difficulties of establishing stands under natural rainfall on submarginal lands plagued by water quality and quantity problems may yet persist.

Best propagation results have been obtained in plantations established by transplanting seedlings so that plants are evenly spaced at a predetermined density. Survival rates in these stands of 80 percent or more is easily obtained which provides competition for uniform stressing needed for rubber formation.

Growing

Growing is the heart of guayule rubber production. It is known that guayule will produce a rubber approximately equal to *Hevea* and that it can be grown as a cultivated crop. What is not yet known is how to cultivate guayule for maximum rubber production at costs competitive with the world economic rubber structure. Costs of establishing guayule stands bear directly upon ultimate production costs, but the ultimate productiveness of the stand is mostly dependent on the efficiency of field operations.

Even a cursory glance at the diagram will make obvious the interrelationships between the various categories and subcategories but the broader aspects of guayule production may not be resolved. Each genetic entity must be subjected to all items affecting the final product; physiological and other specific, basic studies must be carried to the field; finally all aspects of growing must be considered relative to harvesting, milling, rubber quality and quantity, and the worldwide impacts of production.

Harvesting

Experience has shown that the various aspects of growing guayule have

important and far-reaching effects on harvesting and on the rubber produced. Similarly, harvesting must be geared to growing as well as to processing.

Harvesting mechanics are relatively simple, but do offer some options. In general, the usual method of harvest has been to dig or pull the whole plant for harvest, as the roots contain appreciable amounts of rubber. Pollarding, or mowing, appears to have advantages in conducting one or several harvests before digging up the guayule plants. Only limited pollarding trials have been made, however, and little is known about the best time of year for mowing, plant recovery rate, and rubber content of the cut and uncut portions of the shrub.

Shrubs to be harvested will vary greatly because of genetic history and growing conditions. It is believed with some degree of certainty that slowing the rate of growth is essential to generate rubber accumulation in the plant. Cool weather and reduced moisture are most often considered to be the most important conditions to produce rubber accumulation in the plant, but too little is known about rubber synthesis in the plant and empirical procedures will have to be followed. It might be well to reiterate here that no short-cycle (one-five years) harvest has ever closely approached the expected rubber percentage yields predicted on the basis of genetic studies.

Processing

Guayule harvest products are subject to many "treatments" including exposure in the field, storage at the mill, and pre-milling treatments. Experience shows that there should be little delay in getting harvested shrubs to the mill. Similarly storing guayule with or without leaves at

the mill reduces the quantity and/or quality of rubber produced, at least under storage methods tested so far.

Rubber yield percentages peak in younger shrubs (one-four years) at the end of a "stress" period brought on by cool temperatures or reduced moisture. It would appear that the best time to mill out the rubber would be following a stress period, but an extended or even yearlong milling season may be required because of economic considerations. This may be possible because once rubber is produced in living plants it is never lost. Processing problems encountered are related mostly to milling shrubs with varying physiological and anatomical characteristics.

Because of the expected high capital outlays and the relatively high labor requirements compared with growing guayule, milling costs bear an important relationship to production economics.

Processing methods and equipment have been developed on empirical, evolutionary bases, rather than on research findings related to the nature and occurrence of rubber in the guayule plant. The question, therefore, might be raised with respect to modifying current technology and methods to developing an entirely new processing approach, for example solvent extraction alone or removing rubber as latex.

The relationship between agronomic practices and processing alternatives has been shown to be significant. Extracting rubber from very young plants by existing milling processes is difficult and the rubber is lower in quality; the latex method might be better for younger plants. Hybrids

presented many difficulties including high fiber content, leaves too large to remove with available equipment, rubber "worms" too small for effective extraction and in some cases hybrids produced unusable rubber. Each step in milling must be adapted to each variation in the characteristics of the guayule strain to be processed. These characteristics are, in turn, closely related to genetic makeup and growing conditions under which the plant was cultivated.

Products

Much research has been accomplished within the rubber industry on the chemical and rheological properties of guayule rubber. Although guayule rubber green strength differs slightly from that of hevea rubber, slight modifications can be instituted easily in processing guayule rubber to make it essentially interchangeable with other natural rubbers. Monitoring quality and quantity of rubber produced by different strains and under different growing conditions must be maintained to ensure a uniform product that can be used readily by the rubber industry.

In addition to rubber, other products can be obtained from guayule which might affect the commercial value of the plant significantly. Resins are of primary importance among guayule by-products. Studies of the economic potentials of guayule have noted the potential value of the obtainable resins. If chemical and market analyses indicate, it may be that plant breeding programs should concentrate on resin as well as rubber production.

Guayule bagasse, or residual plant material, may have significant

potential as a fuel resource for the milling process. Other potentials include use of bagasse as pulp, as feedstock, as a soil additive or as a base for organic solvent manufacture.

Alcohols, waxes, and low-molecular-weight polyisoprenes also may be economically feasible guayule by-products.

Economics

Economic considerations prevade all aspects of guayule development. Research on combinations of alternative practices is a first-order priority. Propagation, growing, harvesting and processing must be investigated to give production cost ranges, and to indicate optimal alternative combinations.

The world rubber market, its future projections, the relative position of natural rubber in that market compared with heavea supplies, must be investigated with respect to projected costs of guayule development. Findings of this investigation then can indicate what changes might be necessary to promote guayule introduction to the rubber market, and when it would be likely to occur.

Until these economic analyses are completed and the findings injected to influence the other guayule research sectors, little hope exists for successful commercialization of this rubber-producing plant.

Impacts

To accomplish guayule commercialization with minimal adverse environmental, economic, social and institutional impacts, the potential impacts of commercialization alternatives must be assessed as early as possible. Potential impacts will vary greatly depending on the policies adopted by

governmental and private decision-makers involved in achieving commercial guayule development.

Environmental impacts to be assessed include the effects of guayule agricultural practices on soils, water quantity and quality, energy systems, and previously undisturbed arid-region ecosystems. Developing guayule processing plants in the U.S. Southwest could alter air quality, increase industrial water demands, affect water quality through waste disposal, and change industrial sector energy demands.

Socioeconomic impacts of guayule commercialization will relate primarily to food and fiber production trade-offs that could occur, and the market, labor and water-use shifts that might follow large-scale introduction of this crop. Segments of the U.S. Southwest could be altered somewhat, particularly if demographic and economic shifts resulted from introduction of guayule agriculture and processing. Finally, potential quayule development impacts on the world rubber market and countries producing heavea rubber must be scrutinized.

The institutional and political impacts of developing a U.S. domestic source of rubber have received attention. National defense considerations and relative dependence on foreign rubber and petroleum supplies are the primary factors in striving to commercialize guayule. Further in-depth analyses are warranted, however, to determine impacts of alternative political decision, and to assess guayule development impacts on political institutions.

Information Systems

Collecting and exchanging research findings are critical to achieve

a coordinated, interdisciplinary approach to guayule development. Valuable information was collected or developed during the World War II Emergency Rubber Project. Some persons new to guayule research have tended to ignore that body of information. It is critical that research information both past and current, be distributed effectively to those active in guayule research to prevent wasted duplication of effort.

It cannot be overemphasized, as stated in much of the earlier discussion and by the master plan flow chart itself, that researchers involved in the various aspects of guayule development must not operate in isolation. Through comprehensive, interdisciplinary information distribution the entire complex of guayule development can be made available for consideration by the appropriate researchers.

Once research has reached the point where guayule production appears to be economically feasible, it will be necessary to effect information dissemination programs to make research results available to potential national and international producers. Information dissemination programs exist that can forward guayule production information to agricultural and Indian groups in the United States, as well as to potential producers in other countries. Organizations operating these information programs must be used to disseminate guayule information at the appropriate time.

THE PLANT

ANATOMY
- Characteristics
  - size
  - form
    - shape
    - branching
    - leafyness
- Rubber placement
  - stems
  - roots
  - branches
  - leaves
  - flowers and seed
- Processability
  - correlate with milling tests

PHYSIOLOGY
- Growth rate
  - bioinduction
  - microrhizal effects
- Rubber synthesis
  - pathway manipulation
  - stressing regimes
- Photosynthetic response
- Respiration
- Transpiration
- Insect and Disease relationships

GENETICS
- Genetic Constitution
  - apomyxis
  - hybridization potentials
  - cytogenetics
- Breeding and Selection
  - rubber yield
  - by-products
    - resins
    - alcohols
    - waxes
  - disease and insect resistance
  - cold tolerance
    - range extension
  - growth characteristics
    - form
    - processability
  - salt resistance
  - drought tolerance

GROWING CONDITIONS

CLIMATE
- Rainfall
  - amount
  - seasonality
- Temperature
  - minimum level tolerable
  - optimum
  - length of season
- Light Intensity
- Day Length

SOILS
- Texture
- Depth
- Permeability drainage
- pH and salinity
- Soil moisture
  - growth
  - stressing
  - mechanical access
- Fertility
- Microorganisms
  - microrhizae
  - nitritive bacteria

WATER
- Dryland or Irrigated farming
- Available water
  - quality
  - quantity
- Required water
  - quality
  - quantity
    - minimum
    - maximum
- Timing
  - propagation
  - growth
  - stressing

BIOLOGICAL CONSTRAINTS
- Weeds
  - chemical contro
  - guayule toler to herbicide
  - pre-planting treatment
  - mechanical con
    - working
    - pre-planting
  - biological contr
    - layout
  - costs of control
- Diseases
  - identification
  - geographic occ
  - pathogen poten (from other co
  - controls
    - chemical
    - mechanical
    - biological
    - cultural
- Insects
  - identification
  - controls
  - geographic occ
- Vertebrates
  - rodents
  - rabbits
  - domestic stock

PROPAGATION

SEEDLING

ALTERNATE PROCEDURES

GUAYULE

PRODUCTION

PRODUCTS

RUBBER

- Characteristics
  - molecular weight
  - molecular weight distribution
  - gel content
  - structure and stereochemistry
  - branching
  - presence or absence of C=O
- Rheological properties
  - green strength
  - shear strength
  - chemical strength
- Comparative analysis
  - rapid field technique
- Quality and Quantity differential
  - by plant variety
  - by cultural practices
  - by process methods

BY-PRODUCTS

- Resins
- Alcohols & wax composition, purity and value
- Bagasse
  - fuel, net value including drying
  - pulp
  - soil additive or feed
- Leaves
  - as feed or soil additive
- Organic solvent
  - from wastes
- Low molecular weight polyisoprene
- Energy linkages

E

PRODUCTION COSTS

- Alternative agronomic costs
  - production systems
  - nursery / greenhouse / field propagation
  - irrigated / dryland
  - harvesting alternatives
- Processing alternatives costs
  - partial field processing
  - agglomeration
  - latex extraction
  - solvent processing
  - by-product processing
- Transportation costs
  - field-to-processing plant distance
- Marketing costs
- Changes required for competitive pricing
  - rubber percentage
  - shrub weight per acre
  - alternative practices

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sites)

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GROWING

:ONOMICS

EMAND

ıbber market
- % natural rubber
- world market prices
- supply/demand over time
- products
- market values
- quantity demands

COMPETITION

HEVEA
- Disease control
- Labor costs
- Price flexibility
- Pounds/acre potentials
- Plantation expansion
  - Africa
  - Brazil

SYNTHETICS
- Petroleum costs
  - raw materials
- Cis-polyisoprene
  - costs & character
- Other synthetics
  - costs & character
    - styrene-butadiene
    - poly-butadiene
    - polyiso-butylene
    - ethylene-propolenediene

IMPACTS

ENVIRONMENTAL
- Agricultural practices
  - soils
  - water levels in and regions
  - agricultural development vs. and environment retention
  - chemical applications
    - insect control
    - disease control
    - weed control
    - bio-induction
  - energy demands
  - fertilizer application
- Processing plant operations
  - air quality
  - water consumption & waste disposal
  - solid waste impacts
  - energy requirements, sources

ECONOMIC
- Guayule production costs vs. world rubber demand
- Ranges of costs
  - production
  - processing
- By-product markets
  - value/demand relationships
- Effects on established rubber industry
- Effects on agricultural market

SOCIAL
- Demographic
  - agricultural labor
  - processing labor
- Human values
  - ethnic groups
  - health
  - aesthetics
- Land Use trade offs
  - food/fiber/wood/rubber
  - water demand patterns

INSTITUTIONAL/ POLITICAL
- Policy implications
  - economic drive vs government intervention
- Domestic effects
  - national defense
  - vulnerability to foreign supplies
  - effects on levels of government
- International effects
  - trade relations balance of payments oil/food/rubber/etc./
  - utilization in other and regions
    - social, economic, environmental effects there

ıRVESTING

PROCESSING

PRODUCTION

SEED COLLECTION
- Timing
- Methods
- Collection
- Analysis
  - filled seed
  - germination %
- Selection
  - germ plasm
  - field production

STORAGE AND HANDLING
- Clean
- Thresh
- Store
  - short term
  - long term
- Treat to break dormancy
- Treat for disease control
- Microrhizal innoculation
- Pregermination
- Timing

GREENHOUSE PLANTING
- Planting medium
  - mixture
  - sterilization
- Seeding
- Water application
- Temperature
- Humidity
- Light intensity
- Insect & disease control
- Mechanization
  - equipment
  - potting
- Hardening
- Transfer timing
- Costs to field

NURSERY PLANTING
- Soil
  - particle distribution
  - salinity
- Layout
- Seed bed preparation
- Seeding
- Water regimen
  - equipment
  - timing
  - quantities
  - quality
- Temperature
- Weed control
  - mechanical
  - chemical
- Fertilization
- Top pruning
- Disease/insect control
- Prep. for Transfer
  - timing
  - storage
  - hardening
  - mowing
  - lifting
  - antitranspirants
- Costs to field

DIRECT FIELD PLANTING
- Seedbed preparation
  - pre-irrigation
  - weeding
- Layout & spacing
- Planting technique
- Soil
  - particle distribution
  - salinity
  - preparation
- Water regimen
  - equipment
  - timing
  - quantities
  - quality
- Timing: temperature and precipitation cycles
- Weed control
  - mechanical
  - chemical
- Fertilization
- Disease/insect control
- Equipment
- Costs of establishment

(Cuttings & Tissue Culture)

COLLECTION
- Selection of Plant Material
- Characteristics
  - vigor
  - rubber %
  - by-products %
  - disease free
  - cold tolerant
- Timing

TREATMENT
- For Storage
- For Growth stimulation
- Innoculation
  - microrhizal
- For Disease control

ESTABLISHMENT
- Growth medium
- Layout
- Maintenance
  - water
  - temperature
  - weed control
    - mechanical
    - chemical
  - insect/disease control
  - fertilization
- Preparation for Transfer and Field
  - storage
  - timing
  - hardening
  - lifting
- Costs to field

SITE SELECTION
- Suitability
  - climate
  - topography
  - soils
- Field Design
  - spacing & density
    - harvesting techniques
    - processing costs
    - weed control
    - mechanical access
    - irrigation

PREPARATION
- Clearing
- Leveling
- Irrigation facilities
- Ground preparation
  - mechanical
  - chemical

PLANTING
- Direct seeding
- Transplanting
  - equipment
  - care
- Survival
- Replanting or thinning
- Fertilization

CULTURE
- Irrigation management
- Water requirements
  - for establishment
  - for growing
  - systems design
  - timing
  - quantity
  - quality
    - salinity
  - length of cropping
  - costs/returns
- Dryland farming
  - quantities and timing of precipitation
  - length of cropping
  - costs/returns
- Weed control
  - cultivation
  - herbicides
- Disease control
- Insect control
- Physiological impacts
  - cold damage
  - soil aeration
  - shade

PRE-HARVEST CONDITIONING
- Growth regulation
  - canopy cover
  - stressing
- Rubber analyses
  - quantity
  - quality

METHODS
- Digging
  - timing
  - depth of plant desired
  - collection equipment
- Pollarding
  - timing
  - rate of grow-back
  - characteristics of regenerated plant
    - vigor
    - rubber %
    - by-products %
- Combination Pollarding/digging
  - optimum cycle
- Comparison of yields per annum
- Collection and Transportation
  - baling
  - shredding
  - cutting

TIMING
- Optimum harve
- Relationship to Processing Pla
  - maintaining
- Mixed-Age stan
  - viability
  - managemen

INFORMATION SYSTEMS

EXCHANGE
- Research organization
  - interties among researchers
- Flow of research results
  - coordination
    - receive wanted info.
    - avoid superfluous info.
- External
  - information flow with tangentially related projects/programs

COLLECTION
- Gathering
- Classification and indexing
- Computerization
- Establishment of dissemination procedures

DISSEMINATION
- National
  - results to potential producers
    - farmers through Agricultural Extension
    - indian groups through NADSAT
  - results to policy makers and public
- International
  - results to potential user nations, private producers/developers
  - publications in international journals

rations

CONDITIONING

- Stressing
  - temperature
  - water
    - irrigation withholding
    - precipitation cycle
  - bioregulators
- Plant moisture
  - level at harvest
- Chemical defoliation
  - desirability
  - feasibility

STORAGE

- Harvest-to-process time
  - operational season of mill & harvest
  - extension of harvest season
- Product change during storage
  - change in rubber quality/quantity
  - change in resin molecule
- Preparation
  - whole shrub
  - defoliation
    - volume reduction
    - by-product content effects
  - retting

LATEX PROCESS

- Maceration of shrub & latex dispersion
- Stabilization of Dispersion
- Separation into Latex and Serum
- Antioxidants
- Rubber recovery
  - quality
  - % rubber
  - mode of recovery
- Residual rubber in bagasse

AGGLOMERATION PROCESS

- Parboiling
  - defoliation
  - rubber coagulation
  - shrub cleaning
- Comminution
  - rolling and crushing
  - maceration
- Deresination of shrub
  - resin recovery
- Milling
  - pebble (ore & paint indust.)
  - Bauer or Jordan (pulp industry)
- Flotation
  - separate "worms" from bagasse
- Pressure treatment
  - "biaca" vessel
- Secondary Flotation
  - separate cork
- Chemical Treatment
  - worm deresination, antioxidant
  - solvent & rubber purification
- Drying
  - temperature & evaporation systems
- Quality & quantity of rubber extracted

OTHER PROCESSES

- Solvent Process
  - parboiling
  - defoliation
  - deresination
  - rubber solvent extraction
  - solvent recovery
  - drying
  - quality and quantity of rubber extracted
- Field Processing (partial)
  - defoliation
  - maceration
- Portable Processing units

BY-PRODUCT PROCESSING

- Resin recovery
- Alcohols recovery
- Bagasse utilization
  - fuel
  - pulp
  - feedstock
- Whole residue as fuel stock
- Waxes
- Organic solvent production