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# ENERGY FARMING IN BRAZIL: THE ROLE OF AGROFORESTRY ON THE PRODUCTION OF FOOD AND ENERGY FROM BIOMASS IN SOUTHEAST BAHIA

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Solar energy captured by plants through photosynthesis is not only the prime source of all of the world's foodstuffs but also is important in the generation of fuels. The main role of agriculture has always been the production of foods and fibers for mankind. In recent years, however, as a consequence of the oil crisis and the depletion of the world resources of fossil fuels, plant cultivation aimed at fuel production has been considered as a feasible alternative energy source, especially in tropical countries where solar energy is abundant.

This paper analyzes the problem of fuel production from plants, on the basis of information drawn from the literature and from case studies conducted in



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Brazil. Special reference is made to the production of charcoal and the production of alcohol and vegetable oils to replace gasoline and Diesel fuel in internal combustion engines. The potentialities and socio-economic implications of energy farming are discussed.

Because diversified plant communities are more stable than monocropping systems in terms of prevention of soil degradation by erosion and leaching, agroforestry is the safest and the most attractive system for the combined production of food and energy from plants in the humid tropics. Agroforestry is especially interesting in the establishment of perennial energy crops, because it provides earlier cash returns.

## 1. INTRODUCTION

The energy problems of mankind have never deserved so much attention and discussion as in the present days. It has been well known for many years that these problems would become critical in time, due to increasing world population and energy consumption per capita. As a consequence of the oil crisis which emerged in 1973, a new challenge was imposed on countries dependent on fossil fuel imports: the search for alternative sources of energy. One promising source is undoubtedly solar radiation, which is not only abundant, but also inexhaustible.

Solar radiation can be captured either as caloric energy or as electromagnetic energy. The processes for collecting solar energy as heat have thus far received more attention, thermal devices of various types being commonly employed for drying, building conditioning and refrigeration. The present work will deal only with electromagnetic collection of solar energy, more specifically with the utilization of solar energy via photosynthesis, the oldest and most important natural way of "harvesting the sun."

## 2. POTENTIAL CROP PRODUCTIVITY IN THE TROPICS

It is well known that solar radiation is the environmental factor which sets the limit of potential biological productivity of a given region. Many undesirable environmental factors, such as plant diseases and pests, low soil fertility, moisture deficits and/or excesses, etc. often prevent the full realization of the agricultural potential of a region. These negative factors, however, can in many cases be economically controlled by man, especially when growing highly valued crops. Since no economical way

of increasing solar radiation under field conditions is yet known, this factor becomes theoretically the most critical one in defining the potential plant productivity in any region.

Because plant growth in the tropics is so much enhanced by the abundant solar radiation, responses to cultural practices like fertilizer application, irrigation and others, tend to be much more pronounced in tropical than in temperate climates. Of course, during summer days temperate zones may receive practically the same amount of solar energy, or even more than in the tropics, and plants in these regions also respond proportionally to cultural practices. The favorable period of growth in temperate climates is limited, however, to a relatively short season, whilst in the tropics favorable conditions occur almost throughout the year. Thus it can be expected that increases in crop yields due to adequate cultural practices should as a rule be greater in tropical than in temperate or cold regions.

Figure 1 illustrates the above theoretical considerations concerning the potential productivity of tropical zones. In this figure the distribution of incident solar energy as a function of latitude is plotted against estimates of potential biological productivity. Unfortunately, the infor-

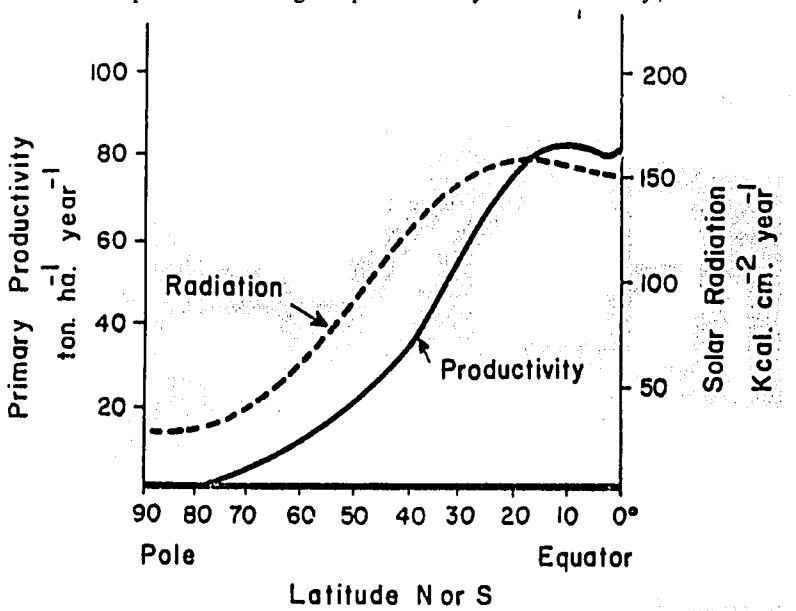


FIGURE 1. Approximate values of potential primary productivity in relation to the latitude.

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mation on photosynthetic efficiency in the tropics is meager. The data presented in Figure 1 were obtained considering a fixation of incident energy of 1% to the latitude of 50° and one of 2% to the tropical latitudes (10°-20°). The actual values found so far are generally lower and average 0.5-1%, but a few isolated cases are known of highly efficient crops like sugar cane, in which an annual primary productivity exceeding 90 tons of dry matter per hectare have been recorded.[1]

These considerations lead to the conclusion that a higher crop productivity can be obtained in tropical regions than in temperate, provided suitable plant material and adequate cultural practices are adopted.

## 3. ENERGY CROPS

Because of the oil crisis and of the progressive decline of fossil resources, plant cultivation for the purpose of fuel production has been considered in recent years, as an additional role for agriculture in certain regions. As previously mentioned, this alternative is particularly interesting in tropical countries having large land availability. In such countries the available land can be exploited with a special type of agriculture dedicated to the production of substances which can be economically transformed into fuels. The "energy crops" chosen for this kind of agriculture are characterized by an ability to produce large quantities of carbohydrates (cellulose, starch, sugars) or oils. Some crops which are able to produce hydrocarbons also deserve attention, although their energetic output is lower than that of the species which yield carbohydrates and oils. The problem of fuel production from these various energy crops is analyzed in the following sections.

### 3.1 Carbohydrate Producing Crops

The most interesting plants having a high carbohydrate storage capacity in tropical countries are sugar cane, cassava and eucalyptus. In Northeast Brazil there is also some interest in the native palm "babaçu" (*Orbygnia speciosa*) which occurs in large natural stands, especially in the State of Maranhão where this palm is found in an area exceeding 10 million hectares.[2] Sugar cane and cassava are undoubtedly the most appropriate energy crops for the production of ethanol, while eucalyptus is mainly recommended for the preparation of firewood and charcoal.

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Comparative data on annual field production and the yields of ethanol from the principal carbohydrate producing crops are given in Tables I and II.

Because of their higher yields when compared with other crops, cassava and sugar cane are the plants selected to support the initial stages of the Brazilian Plan for Alcohol Production. As shown in Table III, this plan is programing an increasing production of ethanol to be used

TABLE I

Estimated Annual Production of Various Carbohydrate Sources in Brazil (Menezes et al., 1977)[25]

| Carbohydrate source | Production (million tons) | Productivity (ton/ha) | |
|---|---|---|---|
| | | Raw Material* | Carbohydrate |
| Sugar cane | 95 | 45 (80) | 5.7 |
| Cassava | 26 | 13 (25) | 4.3 |
| Sweet potato | 2 | 15 (25) | 4.1 |
| Maize | 17 | 1.4 (3.0) | 1.1 |
| "Babaçu" | 140 (?) | 10 (?) | 1.7 |
| Sweet sorghum | (?) | 25 (35) | 3.9 |

*Data on productivity represent the Brazilian national average obtained with the use of traditional cultivation methods; numbers in brackets are the average productivities which can be reached with improved cultural practices.

TABLE II

Ethanol Production from the Main Carbohydrate Sources in Brazil (Menezes, et al., 1977)[25]

| Carbohydrate source | Raw Material (ton/ha) | Ethanol Production* | |
|---|---|---|---|
| | | l/ton | l/ha |
| Sugar cane | 45 | 67 | 3,015 |
| Cassava | 13 | 180 | 2,340 |
| Sweet potato | 15 | 125 | 1,875 |
| "Babaçu" | 10 | 86 | 860 |
| Sweet sorghum | 25 | 85 | 2,125 |

*Industrial production, which corresponds to 77% of the theoretically expected yield.

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TABLE III

**Area Required by the Brazilian Plan for Alcohol Production with Estimated Ethanol Production and Number of Families which will Benefit from the Program (J. G. da Silva, 1978)[3]**

| Phase | | Alcohol Production Target ($10^6$ l) | Required Area[a] (1,000 ha) | No. of families receiving benefits[b] |
|---|---|---|---|---|
| First | 1975-1980 | 2,000 | 677 | 43,312 |
| Second | 1980-1990 | 23,000 | 7,784 | 486,544 |
| Third | 1990-2000 | 45,000 | 15,231 | 951,937 |
| TOTAL | | 70,000 | 23,692 | 1,480,793 |

[a]The following figures were considered: (1) ethanol production from sugar cane: 3,546 l/ha year; (2) ethanol production from cassava: 2,532 l/ha year.
[b]Modules of 16 ha per family.
[a]and [b]It is considered that half of the ethanol is produced from cassava and half from sugar cane.

initially in a 20% mixture with gasoline and ultimately to replace this fuel in internal combustion engines. It is expected that an annual production of 70 billion liters of ethanol will be reached by the year 2000 to meet the projected demand for that year. The plan will benefit about 1.5 million families and will operate on approximately 24 million hectares. This area corresponds to 2.3% of the country's total area (850 million ha), or 7% of the arable land (340 million ha). It is estimated that the area to be used for food and fiber production will be of approximately 100 million hectares by the year 2000.[3]

Cassava's contribution to the Brazilian Plan for Alcohol Production is still relatively small, since the first industrial plant for this purpose has just started operating. In addition, alcohol production from sugar cane is more traditional and crop technology is much more advanced than in the case of cassava. Cassava, however, shows a few advantages when compared to sugar cane such as lower soil fertility requirement, lower cost of production and the possibility of storing the raw material.

The production of alcohol from wood can be economically feasible under certain conditions. In Brazil, however, eucalyptus has been planted with the purpose of charcoal production to be used as a reducer in the iron industry. The Brazilian Smeltery Plan is programing a considerable expansion within a period of 4-5 years with an annual target of 30 million tons of iron. To meet this target, an annual importation amount-

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ing 24 million tons of coke would be required, although this can be partly satisfied with charcoal. To comply with the demand for charcoal several areas are being cultivated with eucalyptus. In the State of Minas Gerais, for example, reforestation will cover an area which will render 3.6 million tons (15 million $m^3$) of charcoal per year. Almost 2 million ha of eucalyptus will be needed in this State to produce 10 million tons of iron. Several by-products are obtained during wood combustion like methanol, acetic acid and combustible gases which significantly reduce the cost of charcoal production.[4]

Alcohol yields from the "babaçu" palm are very low. The starch content of its fruit mesocarp is small when compared with other carbohydrate producing crops, but this is compensated by the large areas existing in Brazil which produce about 140 million tons of fruits per year (Table II). In addition, other products can be obtained from this palm such as oil from the seeds and combustible gases and charcoal from the pericarp (Table IV). The cost of harvesting and transport of the fruits is the main difficulty limiting immediate exploitation of "babaçu" as an energy crop.

Many other forest species, besides eucalyptus, will contribute to the production of energetic substances in tropical regions. It is worth mentioning, for example, the excellent results obtained with *Gmelina arborea* and *Pinus caribea* in the Brazilian Amazon. The "Jari Agroflorestal" has implanted, in the past 10 years, about 60,000 ha of *Gmelina* and 30,000 ha of *Pinus caribea*. The first plantings have averaged an annual wood productivity of 30 $m^3$ of *Gmelina* and 27 $m^3$ of *Pinus* per ha. These levels of productivity come near to the highest commercial wood produc-

**TABLE IV**

**Energetic Utilization of "Babaçu" (Carioca and Soares, 1978)[2]**

| Fuel | Productivity (ton/ha) | Crude Oil Equivalent (ton) | % Energy |
|---|---|---|---|
| Charcoal | 13.5 | 10.8 | 30.1 |
| Gas | 18.9 | 11.3 | 35.9 |
| Ethanol | 13.6 | 8.3 | 27.6 |
| Oil | 4.3 | 0.8 | 5.4 |

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tivity in the world and clearly demonstrate the enormous potentiality of the Amazon Region with respect to commercial wood production.

### 3.2 Oil Producing Plants

The African oil palm (*Elaeis guineensis*) is undoubtedly the most efficient oil producing plant in the world in terms of oil yield per unit cropped land. This crop can easily render 4-5 tons of oil per ha/year under ecologically favorable conditions and with the use of adequate cultural practices. Other species which are also cultivated for oil production such as soybean (*Glycine max*), peanut (*Arachis hypogea*), and castor bean (*Ricinus communis*) are much less productive. The coconut palm (*Cocos nucifera*) can also produce large quantities of oil but does not compare with the oil palm in average figures.

Fuel production from palm oil is much simpler than ethanol production from carbohydrates. The oil contained by fruit pressing is mainly constituted of triglycerides formed by the esterification of fatty acids with glycerine. By heating (30-40°C) the oil for a few hours in the presence of a monoalcohol and hydrochloric acid, the fatty acids can be reesterified and give up an equal amount of oil which is fusible at lower temperatures and can be used as motor fuel in Diesel engines. The monoalcohol can be either methanol or ethanol and is partially recovered in the process. The production of methyl esters following alcoholisis of the oil palm triglycerides is more interesting because, as opposed to the case where ethyl esters are prepared, the methyl esters are naturally separated and a final distillation is not necessary.[5,6 7]

The processes for obtaining ethyl alcohol from sugar cane and cassava are compared, in Tables V and VI, with the extraction of palm oil, from which an equal amount of motor fuel can be prepared by alcoholisis and reesterification as described above. As shown in these tables, fuel production from oil palm is a very simple process which has the following advantages when compared to alcohol production from carbohydrates:

1. higher fuel yield;
2. saccharification, fermentation and distillation processes are not necessary;
3. smaller process heat requirement especially because distillation is not needed;

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TABLE V

**Industrial Processes in the Production of Fuels from Sugar Cane, Cassava and Oil Palm (Barreto, 1977)[26]**

| SUGAR CANE | | CASSAVA | OIL PALM |
|---|---|---|---|
| Harvesting | | Harvesting | Harvesting |
| Crushing | Heat → | Washing<br>Peeling<br>Grinding<br>Cooking | Crushing<br>Pressing<br>Purification<br>Stabilization |
| Preparation of must<br>Fermentation<br>Distillation | ← Heat → | Saccharification<br>Preparation of must<br>Fermentation<br>Distillation | Alcoholisis<br>and<br>Reesterification |
| ETHANOL | | ETHANOL | ESTERS OF FATTY ACIDS |

TABLE VI

Average Fuel Production from Sugar Cane, Cassava and Oil Palm

| SUGAR CANE | CASSAVA | OIL PALM |
|---|---|---|
| 50 ton/ha (stalks) | 15 ton/ha (roots) | 20 ton/ha (fruits) |
| ↓ | ↓ | ↓ |
| Sugar 4 ton | Starch 4.5 ton | Oil 4 ton |
| ↓ | ↓ | ↓ |
| Alcohol 2.8 ton | Alcohol 2.5 ton | Esters of fatty acids 4 ton |

4. smaller volumes are handled. Alcohol production from sugar cane and cassava involves the manipulation of an enormous volume of fermented material, the end-product (ethanol) corresponding only to 10% of such material.[1] Each kilogram of fuel as obtained from palm oil, on the other hand, results from the reaction of 1 kg of vegatal oil with 1.85 g of alcohol and 20 g of acid;[7]

5. no pollutant residues are formed as in the case of alcoholic fermentation. On the contrary crop residues from oil extraction can be used for feeds or to be readily applied to the soil as fertilizer. Their use as fertilizer would consist in a further advantage in that mineral nutrients would be perfectly recycled since the oily material removed from the field is composed solely of carbon, hydrogen and oxygen which originate in the water and in the air. Nutrient recycling in the cases of sugar cane and cassava cannot be readily performed due to the acidic nature of the industrial residues and to the large volume of water to be transferred back to the field;

6. as opposed to the cropping patterns of sugar cane and cassava, oil palm fruits are produced throughout the year and this allows for more efficient use of the industrial plant.

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Provisional data show that the Brazilian demand for gasoline and Diesel oil could be satisfied with the annual production of approximately 20 million tons of palm oil. The area needed would be, theoretically 4 to 5 million hectares, which is equivalent to nearly 0.5% of the country's total area.

Because Brazil is the world's greatest castor-oil producing country, the castor-oil plant (*Ricinus communis*) has also been considered as an alternative energy source. In fact, some buses in the capital city Brasilia are presently using as fuel, on an experimental basis, a mixture of ethanol and castor-oil.

### 3.3 Hydrocarbon Producing Plants

Some plants are able to store solar energy in the form of very reduced carbon compounds: the hydrocarbons. This is the case, for example, with the rubber-tree (*Hevea brasiliensis*) whose latex consists of an aqueous emulsion containing approximately 30% hydrocarbons, mainly polyterpenes made of 1,000-5,000 isoprene units forming a long chain. Through special chemical treatments it is possible to crack these chains to obtain hydrocarbons similar to those found in gasoline. This process, however, would not be recommended in the case of *Hevea* hydrocarbons due to their high industrial value as elastomers. There are, however, many other plants, especially in the family of the Euphorbiaceae, that also produce hydrocarbons which can be transformed into fuel and which do not have such a high economic value as the latex obtained from the rubber-tree. One such species is presently being studied in Brazil with a view to fuel production. It grows in the arid zones of Northeastern Brazil where it is commonly known as "aveloz" (*Euphorbia tirucalli*) and is used for fencing. The plant produces a latex formed of low molecular weight terpenes and terpenoids which can be converted by "cracking into a gasoline-like fuel as well as into ethylene for industrial purposes.[8]

The essential oils produced by some plants also contain a considerable quantity of hydrocarbons (terpenes and terpenoids) which can equally be transformed into motor fuel. One promising species that is being studied in Brazil for this purpose is *Croton sonderianus*, the "marmeleiro preto," a wide-spread invader of the Northeastern region. Unfortunately, no information is available concerning its agronomical potentiality, but it is estimated that this plant can produce about 200 tons fresh weight

## TABLE VII

**Annual Fuel Production from Various Sources in Relation to their Average Productivity in Brazil**

| Fuels | Source | Productivity | | |
|---|---|---|---|---|
| | | ton/ha | l/ha | l/ton |
| ALCOHOL | SUGAR CANE *(Saccharum officinarum)* | 45 | 3,015 | 67 |
| ALCOHOL | CASSAVA *(Manihot esculenta)* | 12 | 2,160 | 180 |
| ALCOHOL | "BABAÇU" *(Orbygnia speciosa)* | 3 | 240 | 80 |
| ALCOHOL | SWEET POTATO *(Ipomoea batatas)* | 15 | 1,875 | 125 |
| ALCOHOL | SWEET SORGHUM *(Sorghum saccaratus)* | 25 | 2,125 | 85 |
| HYDROCARBONS | "AVELOZ" *(Euphorbia tirucalli)* | ? | 640/3,200+ | ? |
| TERPENES | "MARMELEIRO" *(Croton sonderianus)* | ? | 400/2,000+ | 10 |
| OILS (Triglycerides) | OIL PALM *(Elaeis guineensis)* | 20 | 4,000 | 200 |
| TERPENOIDS | KEROSENE TREE *(Ocotea barcellensis)* | ? | ? | ? |

+Estimated yields, not supported by experimental work.

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of biomass per hectare. Preliminary observations have shown that the oil content corresponds to 1% of the biomass on a fresh weight basis. Consequently, two tons of essential oils could be obtained per hectare. The oils are obtained from the whole plant tissues through steam extraction followed by condensation and water separation.[9]

As a curiosity it is worth mentioning a native tree of the Amazon Region locally called "kerosene tree" or "louro mamori" (*Ocotea barcellensis*), from which the Indians extract an oil having a strong terebinthine scent that can be used as a fuel for domestic purpose instead of kerosene.[10] The oil is extracted by making a hole in the main trunk. Unfortunately no reliable information is available regarding the potential productivity or cultural characteristics of this curious oil producing tree.

Table VII summarizes general information on the energetic potentialities of the main plants mentioned in this paper.

## 4. THE CHALLENGES OF ENERGY FARMING

Energy farming will be particularly interesting for countries which are largely dependent on fossil fuel importation and possess an extensive area of arable land. These countries will have the opportunity to decide whether or not to keep importing fossil fuels. Even if the production of fuel from vegetal matter is marginally more expensive than the importation of fossil fuels, it may remain an attractive proposition when the advantage of additional rural employment is considered. The choice between fossil fuel importation and internal fuel generation from plant sources will be depending then on the internal economic policy of the country.

With the decrease in fossil energy reserves, however, the future economic picture becomes more and more complex and new problems may be imposed. In view of the need to feed an increasing population, it is believed that land occupation in the future will have to be programmed more carefully, taking into consideration the critical equilibrium between food production and energy farming.

With regard to the food-and-people relationship it is important to consider future trends in the use of animal and vegetal foods. Because of the increasing population pressure it is believed that a wider competition will occur between tillable and grazing land. Plants are the fundamental link in the trophic chain of a balanced ecosystem, and their

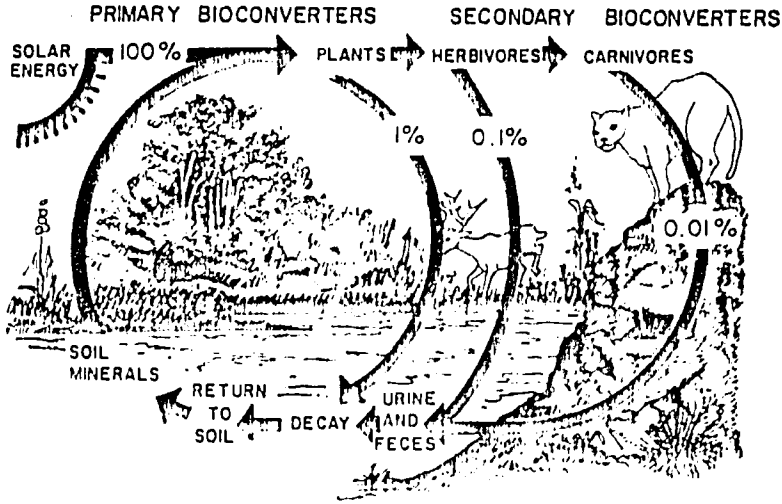


FIGURE 2. Relative efficiency of the primary (plants) and secondary bioconverters (herbivores and carnivores) of a natural ecosystem in capturing solar energy. (Adapted from "Man in the Living Environment." The Institute of Ecology, 1972).

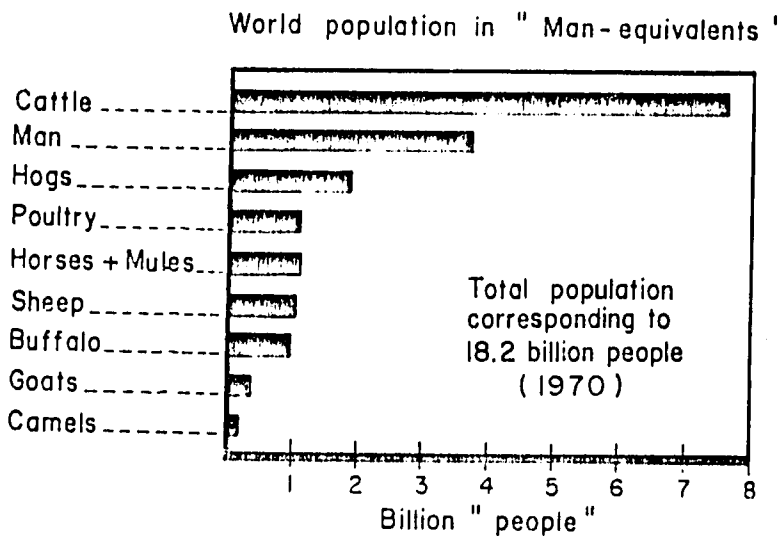


FIGURE 3. Estimated world "population" based on protein consumption of animal competitors to man and expressed in terms of "man-equivalents." (Adapted from 11).

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ability to store solar energy is at least 10 times greater than that of the herbivores and 100 times that of the carnivores (Figures 2). In other words, even the herbivores, which are considered the most efficient animals in terms of land occupation, need at least 10 times more land in order to store the same amount of energy as plants would do. Thus, animals may be viewed, under certain circumstances, as competitors to man, and this is illustrated in Figure 3 which compares the protein consumption of man and of the livestock in the world. This figure is computed on the basis of an average man (70 kg), who requires a daily protein intake of 70 grams, the data being expressed in terms of "man-equivalents." It can be observed in this figure that the cattle biomass is twice that of man. By adding up all the living mass of livestock it can be concluded that there are more than 18 billion "people" in today's world, or 5-fold the real "human" population.[11]

Of course, animal proteins are much more complete for man's nutrition than those found in plants. The great majority of cultivated plants have an inadequate content of sulfur containing amino acids which are essential to a man's balanced diet. Plant breeders have tried to develop varieties having a high content of these amino acids and some maize and sorghum varieties are actually relatively rich in lysine. It is known, however, that animal products will constitute, for many years to come, inevitable supplements to man's diet. But there are more adequate ways of producing and consuming animal proteins than the prevailing one.

With respect to the consumption of animal food, it is worth mentioning the cases of the United States of America, Canada, France and Germany where the annual output of cereals per caput is about 1,000 kg and 900 kg are destined to animal feed. On the other hand in China, where some 200 kg of cereals are annually produced per caput, only 40 kg are used in livestock feed and the remaining 160 kg are directly employed in man's diet.[12]

In fact, a substantial part of mankind hazardously eats an excessively high proportion of animal food, with serious economic and possibly also health consequences, as can be inferred by the higher incidence of heart diseases and cancer in countries where excessive meat is consumed.

With regard to increasing the production of animal protein, the previous reasoning leads to the conclusion that, in the future, it would be inefficient to use potentially tillable land to raise animals, especially with the precarious methods employed in many countries, notably in the tropics. Animal food production should be restricted to marginal land with no practical value for arable purposes.

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Special forage plants are being selected and ameliorated for poorer and drier soild than those suitable for food crops. It is also believed that the methods selected for future production of animal protein will have to rely on better management practices providing adequate recycling of animal and vegetal wastes. Because fish can be fed with crop and animal residues, fish culture is a particularly promising activity with respect to nutrient recycling. Figure 4 shows an integrated farming system designed for the cocoa region of Southeast Bahia to recycle plant and animal wastes. In a brief description, the system aims to generate energy in the form of methane through anaerobic digestion of a mixture of cacao pod husks and cattle manure. Steers are fed in confinement with pod husks. Energy from biogas can be used for several purposes, including to dry cocoa, and the digester effluent can be used either as fertilizer or to feed fish. It is expected that the revenues obtained with biogas, steers, fertilizers, fish and also the cacao jelly which can be made of the pulp juices obtained by pressing the beans following mechanical pod breaking, will far compensate the expenses with whole fruit transportation. It is a current practice to break cacao pods manually in the bushes, leaving the pod husks to decay in the field. This is not good management because the heaps of pod husks are a source of inoculum for the dissemination of cacao diseases. Some figures have already been obtained experimentally. Thus, a farm producing 20 tons of dry cocoa would also produce 133 tons fresh weight of pod husks and 5,555 l of pulp juices. From the latter 3,888 kg of jelly can be prepared. In isolated processes, the pod husks would either render 5,320 $m^3$ of biogas or would be sufficient to feed 2 lots of 7 steers each annually, since cacao is harvested for 8 months per year in Bahia and the method is recommended to fatten steers with initial liveweight of approximately 220 kg for a period of 4 months. This diet is supplemented with 300 g of a 16% protein concentrate per animal per day, producing liveweight gains of 840 g/animal/day (Llamosas, Marques Pereira e Soares—unpublished). The system, however, proposes to share the pod husks as explained above, in a proportion which will vary according to the energy needs of the farm. Over 300,000 l of digester sludge with 24,000 kg of solids would be available, if all pod husks were used for biogas generation, which could be employed either as fertilizer or for fish culture.

Another means of improving the production of animal protein is the utilization of vegetal protein concentrates extracted from crop wastes as a feed for non-ruminants. Since ruminants can utilize plant ingredients

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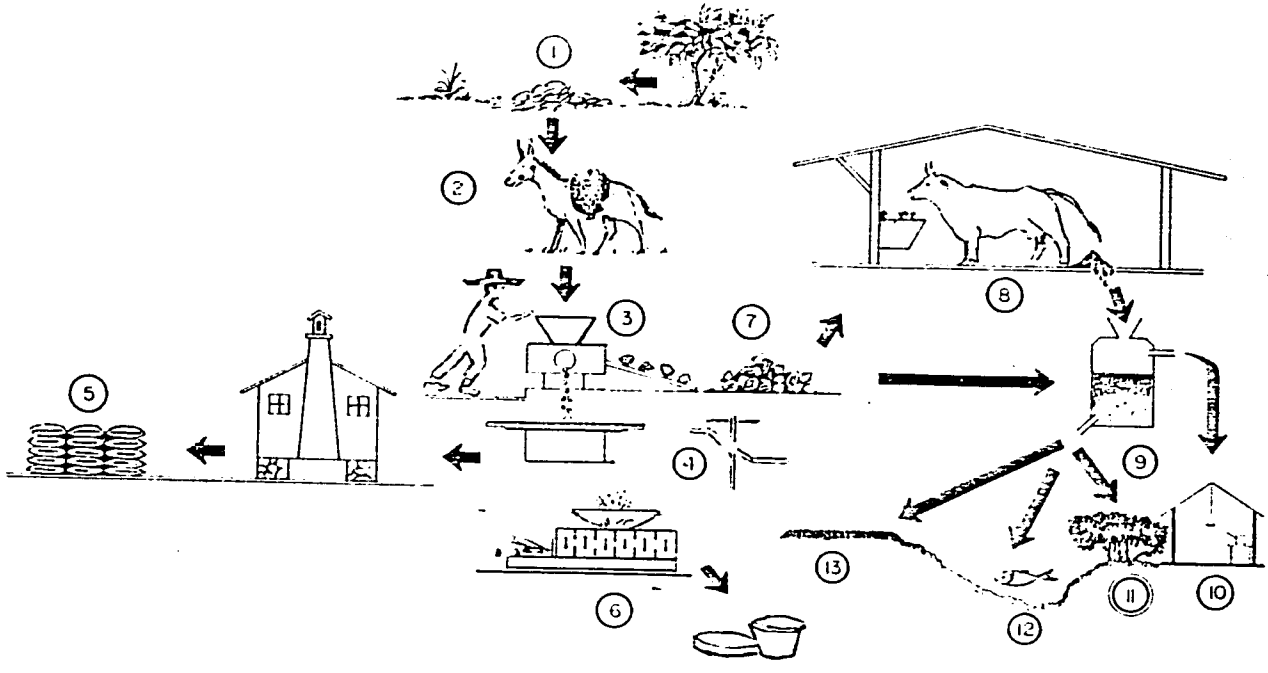


FIGURE 4. Integrated farming system for cacao farms in Bahia: 1-harvesting cacao pods; 2-transporting the whole fruits; 3-pod breaking machine; 4-pressing the beans to obtain pulp juices; 5-cocoa drying; 6-preparing cacao jelly; 7-pod husks; 8-cattle fattening; 9-biogas generation; 10-using biogas for lighting, cooking and other purposes; 11 and 13-using digester effluent as fertilizer; 12-fish culture with digester sludge.

such as cellulose and others that man's gastric system cannot digest, they considerably broaden the basis for human existence through their low-key competition.[11] The non-ruminants, on the other hand, exert a high degree of competition to man but could be used as biological converters of low quality to high-quality protein if fed with crop wastes.

The next problem refers to the selection of the areas to be used in the process of capturing solar radiation with energy crops. It seems logical that the chosen land will be that of marginal qualification for the production of foods, where the soils present some problems for plant growth. This is the case, for example, of the oxisols and ultisols which are abundant in the tropics and can be successfully exploited with crops having low requirements like cassava, eucalyptus and many other woody plants of great energetic potential. Agroforestry will play a role in these areas, especially to avoid soil degradation, as discussed in the following section.

Large scale fuel production from biomass is undoubtedly a new challenge to mankind which will inevitably cause socio-economical changes. One of its possible consequences may be the redistribution of rural and urban population. Because of the large contingent of man-power presently engaged in industrial activities around the majority of the big cities in the world, a great deal of energy is consumed in these cities, mainly with mass transportation. It is expected, however, that the present rate of rural exodus will be limited or restrained due to the additional land occupation for energy farming. It is possible, therefore, that the equilibrium between rural and urban populations is restored in the near future thus, alleviating the energy demand of the large cities.

The production of fuels from biomass is an enormous hope with respect to the future of tropical countries. The abundant fossil fuel resources existing in the past provided the necessary stimulus for the rapid agricultural development in the temperate regions of the world. In spite of the difficulties met by man in temperate zones, where climatic conditions are unfavorable for himself and for the plants during great part of the year, agriculture in these regions is more developed than in the tropics. Taking into consideration the fossil fuel depletion in the world and the enormous potential biological productivity of tropical regions, it is believed that a more balanced wealth distribution will occur in the future as a consequence of fuel production from biomass and that an economical equilibrium between temperate and tropical regions will hopefully be reached.

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## 5. ENERGY FARMING AND AGROFORESTRY

The previous sections were found necessary to introduce the reader to the Brazilian plans for energy production from biomass. In the present section the major subject of this paper is discussed, viz., the potential role of agroforestry in energy farming in the humid tropics, with special reference to the Southeast of the State of Bahia. Due to the extensive period of high intensity rainfall in these regions, it is pertinent to think that trees are an important ecological component of agricultural systems aiming to provide satisfactory soil protection. Multiple cropping with trees as the dominant component is consequently one of the safest systems of land use allowing permanent and remunerative cultivation in humid tropical regions. This argument, of course, does not rule out energy farming in solecrop systems for these regions, providing the crops chosen give sufficient soil protection. The proposition is put forward only to emphasize the advantages of multicropping over monocropping, as recognized by several authors.[13,14,15]

Agroforestry is a new name for an old concept involving multiple cropping, with the integration of woody perennials and crop plants (or grasses), and sometimes animals, on the same unit of land.[16] A typical characteristic of an agroforestry community is, therefore, that it involves two or more species, at least one of which being a woody perennial.

From the ecological point of view agroforestry communities show multiple advantages over the conventional agricultural methods. Agroforestry systems simulate the natural forest and are considered much more efficient than solecrop systems with regard to the prevention of soil degradation by erosion and leaching caused by direct rain impact.[17]

An agroforestry approach to energy farming can involve a wide range of combinations of various species of plants and animals. It seems reasonable, however, to distinguish three basic types of system which seem more promising for energy farming in Southeast Bahia, a region with no definitie dry period, with high temperatures (mean annual of about 23.5°C) and a total rainfall of around 1,700 mm:

1. Food crop production under perennial energy crops;
2. Rotation of trees for fuel and food crops ("taungya" system);
3. Commercial crops shaded by perennial energy crops.

## 5.1 Food Crop Production under Perennial Energy Crops

In this type of agroforestry approach to energy farming, food crops are produced, on a temporary and subsidiary basis, during the period of immaturity of perennial energy crops such as oil palm and many other multipurpose species able to produce large quantities of carbohydrates or oils. The difference with the following case is that the tree crops here are exploited for many years for both food and energy production, whereas in "taungya" systems the trees are harvested in shorter periods of time and are solely used as fuel.

In the case of oil palm, some interesting data drawn from the literature show the potential role of agroforestry systems to subsidize the establishment of this multipurpose crop. In an agroforestry experiment performed by Sparnaajj in Nigeria, oil palm was intercropped for as long as possible with mixed yams, maize and cassava followed by cocoyams as the palmshade developed. Sparnaajj found a net increase in yield of palm fruit, as well as significant production of the food crops. Intercropping stimulated growth in the early years after planting, and thereafter gave increased fruit bunch pr. luction over a period of 12 years of harvesting.[18] A similar experiment is being carried out in Bahia by the Cacao Research Center, in which 16 different species of food crops will be cultivated between rows of young oil palms during the period of establishment of this crop. Food crops were selected according to local customs for both subsistence and early cash returns during the period of immaturity of the palm. A cooperative society was established in the area to assist the farmers with marketing of the different crops and to process the palm fruits either for food or for fuel. In order to improve the economic position of smallholders, research on small scale plants for oil extraction and on replanting uneconomic holdings with high yielding cultivars is currently being undertaken. About 70% of the cropped area with oil palm in Bahia, which is estimated as 20,000 hectares, consists of smallholdings and comprises poor yielding material or old stands. It is expected that all these facilities put together will encourage the farmers and launch the program of oil palm plantation for food and fuel production in Bahia.

This kind of agroforestry can also be employed with other perennial energy crops. For both carbohydrates or oil producing plants, many of the species which will be examined in a following section could be con-

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sidered. But oil palm, as already mentioned, deserves special attention because it is the most efficient energy crop. Indeed, processing costs are around US$ 45.00 per ton of palm oil. Farm energy input is approximately $3 \times 10^6$ kcal · $ha^{-1}$ · $year^{-1}$, whereas the energy output varies from $36 \times 10^6$ to $55 \times 10^6$ kcal · $ha^{-1}$ · $year^{-1}$. Theoretically nearly a 10-fold net energy gain can, therefore, be obtained. The energy balance will be more favorable with intercropping, because the cost of land clearing will be shared, the amount of fertilizers applied to the growing palms can be reduced due to symbiotic fixation of nitrogen by some intercrops and the net energy output of the intercrops will be added to that of the oil palm.

### 5.2 Rotation of Trees for Fuel and Food Crops

The energy shortage in the developing world is not only of liquid fuels but also of wood. The fuelwood crisis in these countries has now been quantified. A study of 15 developing countries[19] has shown that the rate of fuelwood plantation will have to increase from 63,500 hectares to 670,000 hectares per year to avoid a shortage in the year 2000. In another study[20] it has been estimated that if adequate measures are not taken, 3,000 million people will suffer a serious shortage of fuel wood in the year 2000. It is also estimated that 50 million hectares of new fuelwood plantations will have to be established until the year 2000 to alleviate the developing world energy crisis.[21]

As previously commented, Brazil has a solid program of reforestation for energy production with quite ambitious targets. Since this program is almost entirely devoted to charcoal production to be employed in the iron industry, and the large Amazonian reserves of wood are not accessible to most of the population, Brazil is also dependent on substantial quantities of fuelwood for cooking, food processing and industrial purposes. But fuelwood plantation is not an encouraging business except for companies engaged in the country's Smeltery Plan. There is a clear role for agroforestry here, regardless of the size of the holding, to give sufficient incentives for farmers to become foresters. It is obvious that the most direct solution to the fuelwood crisis is a massive program of reforestation to achieve sustained yields of trees for fuel in combination with food crops. In fact, this combination is not a novelty. "Taungya" is the system employed in many tropical countries where labor employed in forestation is permitted to cultivate food crops in between the tree

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crop rows, during the early years of establishment. In return for this facility, the labor keeps the plantation clear of weeds and looks after the young trees.[18]

In Nigeria two types of taungya were reported[22] and compared to direct planting where no food crops are grown: "Departamental Taungya," where any food crops produced are the property of the Forest Department, with settlers being paid for their work, and "traditional taungya," where the food crops belong to the farmer. Departamental taungya costs the Department N 117 per hectare over the two-year establishment period of the tree crop. Traditional taungya costs N 212.5 per hectare. Direct planting, however, costs a lot more: N 525 per hectare. It is obvious that the system is beneficial to the Department and to the farmer. Another advantage of intercropping in the establishment of energy forests is that fertilizers applied to the food crops are partly taken by the trees, which have deeper root systems to recycle these nutrients, and this alleviates the problem of soil depletion or "soil mining." If legumes are used as intercrops the demand for nitrogen by the tree crop can be greatly reduced.

In spite of the large area of reforestation in Brazil, little attention has been paid to species other than eucalyptus and pine. The Cacao Research Center has been studying several tree species in Bahia for many years and is now in a position to suggest some fast growing species to be used in this kind of energy farming besides eucalyptus, such as *Piathymenia foliolosa* ("vinhático"), *Centrolobium* spp. ("putumuju") and *Cordia trichotoma* ("claraíba-parda").

### 5.3 Commercial Crops Shaded by Perennial Energy Crops

Some commercial crops such as cacao, pepper and coffee can be grown under the shade of taller trees. In the case of cacao, the practice is generally accepted as the safest way of managing the plantation, not because shade provides a low light intensity considered optimal for growth and yield, but due to its effects in counteracting unfavorable ecological conditions such as increased incidence of insect pests and low soil fertility. In fact, there is solid evidence that fully exposed cacao produces more than shaded cacao, but the practice of using shade trees is widely accepted by farmers and indeed recommended by research institutes dealing with the crop. In the traditional cacao farms in Bahia, for example, there are on average 79 ± 25 shade trees per hectare.[23]

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Some species are particularly interesting from the economical point of view as potential shade trees for cacao and other shade tolerant crops, especially if multistoreyed system are developed to promote a higher degree of diversification as recommended in agroforestry. The major problem with many of these promising species of potential economic value is that there is little detailed knowledge about them, especially with respect to their yielding capacity. Another problem is marketing of some of them: if large areas are planted, their price will deteriorate, unless an alternative use for them is found. And many could be alternatively used as a source of carbohydrates or oils for fuel.

One of the most important of these species is the peace palm (*Guilielma gasipaes*), also known as "pejybaye," "chontaduro" or "pupunha." This palm is very appreciated for its fruits and for its growing shoots or palm hearts. Peace palms have been found with more than 70 bunches per palm and 50% oil content in the fruit.[18] Other promising palms are "buriti" (*Mauritia flexuosa*) and "batauá" (*Jessenia* spp.). Adult plants of the species *Jessenia polycarpa* can render 30 kg of fruits per annum from which 22 kg of oil are extracted.[17] Palms are especially interesting as a component of multistoreyed systems because many of them tolerate moderate shade and also cast little shade over lower canopies, because of the "Venetian blind" shape of their leaves. In other words, palms are of particular interest as a medium canopy in multistoreyed systems if the top canopy does not throw excessive shade over them. Very tall trees, on the other hand, make lateral light available to lower canopies and could be used as the top canopy in multistoreyed agriculture for energy production. One with a great promising future is the "piquiá" (*Caryocar villosum*), a large tree growing to over 40 m in height which is exploited for its fruits. Two types of oil can be extracted from the fruits of "piquiá." "Copaiba" is another species of interest as a tall top component of multistoreyed systems. The most productive species of "Copaiba" are *Copaifera officinalis* and *Copaifera langsdorffii*, both native of the Amazon region. Its oil, which is extracted by making a hole in the trunk, is produced at an average rate of 3 to 5 liters per annum, but some trees have been found producing 20 to 30 liters.[17]

Some smaller trees also deserve consideration in less diversified agroforestry systems for energy production in combination with commercial crops. The jackfruit (*Artocarpus heterophyllus*) is one of these. The tree reaches about 20 m in height and can produce up to 100 fruits per annum, some of them weighing 40 kg. They are the largest of all cultivated fruits. The edible pulp, which comprises about 30% of the fruit,

has a carbohydrate content of 23.4% fresh weight. Seeds, which constitute about 5% of the fruit, contain 38.4% carbohydrate in fresh weight.[24] Breadfruit (*Artocarpus incisa*) is a tree of the similar height and produces a round seedless fruit weighing from 1 to 5 kg. Its edible portion, which constitutes about 70% of the fruit, also has a high carbohydrate content of about 20% fresh weight. Mature trees yield up to 700 fruits per year.[24] This species can yield up to one ton of fruit per tree per annum.[18] "Jenipapo" (*Genipa americana*) is a South and Central American tree growing to 15-20 m in height. Its fruits, of about 10 cm in diameter, are used in the preparation of alcoholic drinks, and are produced in large quantities. In spite of the lack of detailed information on yield and on accurate content of carbohydrates which could be transformed into liquid fuels, these brief remarks on jackfruit, breadfruit and "jenipapo" indicate the potential use of such trees as perennial energy crops shading the commercial crops.

It is worth repeating that the possibility of growing these same trees in monoculture for energy farming is not being excluded in this paper. The agroforestry approach is presented because of economic and ecological reasons, particularly in the case of cacao, where large plantations are normally shaded by trees of less economic value.

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