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CHEMISTRY, POPULATION, RESOURCES

Melvin Calvin

August 24, 1977

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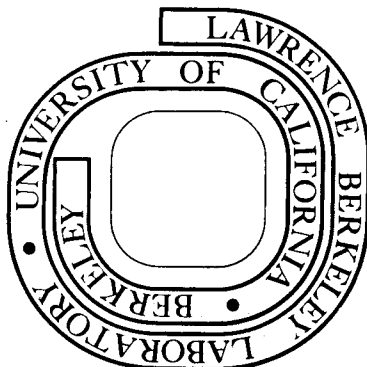
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CHEMISTRY, POPULATION, RESOURCES

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CHEMISTRY, POPULATION, RESOURCES

ABSTRACT

Chemistry plays a central role in the global development not only of the world's human population but of the resources upon which that population depends. Its effect on the growth of human populations has been exercised primarily through the contribution of chemistry to our understanding of (1) production of food and its role in nutrition, (2) the many factors influencing the public health, in the human environment as well as the physical environment, and (3) the progress of our understanding of disease and the concomitant development of medical practice and drugs.

These factors, taken together, have increased the life expectancy at birth of the population throughout the world. For Europe and the United States it has risen from 41 years in 1840 to over 70 years in 1960.

Similar changes have occurred in most of the countries of the world, save certain ones in Africa, and India, Pakistan and China. Although the present life expectancy at birth in these countries is roughly 20 to 30 years less than in the western world, it has undoubtedly improved during the last hundred years. While such an increased life expectancy constitutes a significant social and personal value, it has been a major contributor to explosive growth of the world's population in the last century.

Parallel with this has been the role of chemistry in developing the materials and the energy required by this growing population as well as their growing expectations. The development of new materials, primarily organic, has placed a double strain upon the world's energy resources. We are now feeling the shortage, particularly of fossilized photosynthetic energy,

whose rate of discovery is falling the world over. Chemistry is clearly the core of knowledge required to find replacements.

The mechanism by which these benefits are brought to the people is the chemical-pharmaceutical industry throughout the world. Occasionally the people (or the workers in the industry) are exposed to some toxic material through someone's ignorance or negligence in the practice of the most elementary rules of prudence and safety. These relatively rare events have prompted public bodies (usually legislatures) to enact severely restricting regulatory acts which must be enforced upon the entire industry--knowledgeable and careful as well as the few who might be ignorant or careless. This regulation has the consequence of severely limiting the introduction of new materials and medicines regardless of their risk-benefit ratio. Incongruously, these same societies are not only condoning but supporting the production and consumption of the most widely used health impairing material in the world--the growing and smoking of tobacco. The use of tobacco is perhaps one of the best known and established chemical carcinogen producing human activities we know. Thus, a great deal of effort and money is being extended in the attempt to control (and overcontrol) the relatively rare transgressions (mostly inadvertant) of the chemical-pharmaceutical industry, while direct financial support and encouragement is given for the wide consumption of a well-established health hazard.

As the need for new chemical knowledge grows, the new knowledge which we obtain in response to this demand increases our fundamental understanding of nature, particularly of the (chemical) molecular basis for life itself. This new understanding opens new vistas of thought for defining the relationship of man to nature and of individual men to each other. We thus can

approach in a more realistic way the deepest concerns of mankind and the products of this concern will appear in a multitude of forms--art, literature and other imaginative and human activities--ultimately contributing to the development of a more acceptable social structure around the globe.

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CHEMISTRY, POPULATION, RESOURCES

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INTRODUCTION

Chemistry plays a dominant role in the development of modern human societies over the entire globe. It has done so by virtue of the central position it has occupied in improving the health and nutrition of people, as well as by improving their physical environment by providing the new and necessary amounts of materials for clothing, shelter, transportation, and other such amenities of the modern organized world. As you will see in a few moments, this double role has both its merits and its demerits. As a result, at least in part, of the contributions of chemistry to the improvement of the food and nutrition of the global population (1), as well as a contribution to the improvement of the public health and the health of individuals, the population of the globe has been rising very rapidly, as shown in the first slide (Figure 1).

POPULATION

The projection here is that the population will rise to about seven billion by the year 2000 from a present value of about 3.5 billion. Most of that rise in numbers will clearly take place in Asia, in Africa, and in Latin America. Part of the reason for this differential, of course, is the fact that the rest of the world has already reached some new equilibrium, with

the better living conditions which chemistry has helped to produce, whereas the aforementioned countries are just now reaching it.

One of the ways in which one can evaluate that differential is to note what has happened to the life expectancy at birth in the Western countries, such as the United States and Western Europe, in the last hundred years. This enormous increase in life expectancy from forty to about seventy years in the one hundred years just past, shown in Figure 2, appears now to have reached some kind of new level. The life expectancy in the less developed countries, in which the population growth is expected to take place, is at present some twenty to thirty years less than that shown for the Western world; as these less developed countries improve their public health, nutrition, and medical facilities, they too can expect an increased life expectancy, and therefore have a much higher impact on the population of the world.

One of the factors which has been of major influence on the growth rate of population has been the increased food supply and the better nutrition that has resulted therefrom. Chemistry has played an enormous role in this development by helping to produce the fertilizers that were necessary for the higher production, as well as in playing a role in the food processing and the preservation of food after it is grown. We can expect molecular biology, a specific branch of chemistry, to have an even greater impact on the quality of the crops that will be grown in the coming years; and therefore again we can expect that the productivity of the acreage that we have available will actually increase even more.

AGRICULTURE

The contributions of chemistry to worldwide agriculture and to the increased productivity in all parts of the world is made clear in Figure 3. Here one can see that in all of the four groups of countries shown, the absolute rate of production of food is increasing at very nearly the same rate throughout the world. However, when we look at it in terms of the per capita availability of food, we see that only in the developed countries such as the United States and Western Europe is the actual amount of food per person increasing, whereas in most of the other countries the amount of food per person is barely remaining constant over the last twenty five years. The reason for this is now clear. The food production capability is increasing in all parts of the world at about the same rate, due to the improved technologies. However, the population increase in the less developed countries is increasing even more rapidly, with a consequence that the per capita food available in these places has remained very nearly the same for the last twenty five years. Thus it is clear that the problem is not so much in improving the rate of food production as it is in reducing the rate of population growth. This, also, is a problem to which chemistry will help and contribute. However, chemistry cannot solve the problem by itself. Nevertheless, one can expect that chemistry will play an important role in helping to provide a feasible and useful means by which various societies will not only be able, but willing, to help in the control of their own populations, thus allowing the increased food productivity which chemistry has also provided to increase the available food per person in those countries, thereby also contributing to the increased life expectancy and the health and well-being of the people in them.

One of the ways in which chemistry has been able to improve the productivity of the agricultural community has been to provide it with the necessary fertilizers and other energy-consuming assistants, to improve the yields. This has led to a high energy consumption in those countries in which there is a high food production, and consequently a high gross national product, however one measures it.

ENERGY AND MATERIALS - PRESENT USE

There are various ways to examine this relationship between energy consumption and social values. One way is shown in Figure 4, in which the energy consumption per capita is indicated. Here one sees that the energy consumption per capita is highest in those countries in which the standard of living is highest, such as North America, Western Europe, and Japan, whereas in those countries in which the standard of living (however it may be measured) is low, the energy consumption is low.

Another, and perhaps even more realistic, way of looking at it is to examine Figure 5, in which we show the relationship (at least in the United States) between the value of the gross national product produced by the country per million BTU's (a unit of energy) that it uses. It is clear that, in general, the increased value produced per unit of energy used means a more efficient organizational and structural entity, and this has been the case over the last twenty five years, as is evident in this figure. In fact, part of the reason why the agricultural productivity in the United States has been so bounteous as to be able to be an important aid to the rest of the world has been because of the large input of energy into our agricultural activities. This energy has had its source primarily in the form of fossil energy - namely coal, oil and gas. In recent years, however, it has been dominated by oil

and gas, which are more convenient, and more environmentally acceptable energy sources than coal. However, there is a limit to how much of this fossilized photosynthetic carbon is available, and the limits are already visible - especially in the oil and gas areas.

The next figure (Figure 6) shows the rate of discovery of new oil in the United States as a function of the number of feet of well drilled. It is evident that there has been a sharp decrease in the rate of new discoveries, even though the drilling rate has increased. This decrease began in about 1950, and it is now leading to a total decrease in the net available oil on the American mainland. It can only mean that the available oil to be found in this geographical area has now passed its peak, and that we can only look forward to a decrease in the total amount that we will have available from this source. In fact, we believe that the peak production capability in the continental United States was reached several years ago. It also appears to have been reached on a global scale as well, as shown in Figure 7.

COSTS AND AVAILABILITY

Another different way of making an estimate of the availability of resources is to look at the history of the costs that have been attributed or laid down to a particular resource. In this case, we are considering now the fossilized photosynthetic materials: coal, oil, and gas. In Figure 8, I have shown a price history of these three materials in the United States over the last fifteen years, with a projection of what that price might be in the next four or five years. As you can see, it was fairly constant for a period of about ten years, and then began to rise very sharply - partly for political reasons, and partly for technical reasons of shortage.

The separation of these two factors is not possible for me. In any case, as the price rises the result of that price rise will be a more limited use of the materials, so that we must find other ways of fulfilling our needs. We can hardly expect that the price of oil or gas will ever fall again to anything approaching the values shown in the first ten years of this illustrated period. There is not much question that at least part of the reason for this is the real and total depletion of the stores of such materials that are presently in the Earth. If we accept for the moment the basic premise that most of this oil and gas (if not all of it) was once the product of a living organism, using the sunshine as a source of energy, we can be sure that the amount of it available to us stored in the ground is a limited amount by the standards that we are now using for the rate of its use. In fact, there have been a number of historical analyses of other resources going through a similar use and depletion cycle, and it has been suggested that we are already on the decaying side of the oil depletion curve. Therefore, we can expect it to be truly used up within a relatively short period of history.

The amounts of available coal, however, are globally believed to be much higher. In Figure 9, the two resource use curves are superimposed on each other, and it is clear that the coal resource use curve extends far beyond any limits of technology which we can now perceive. It is for this reason that many of our political leaders, both domestically and internationally, have supposed that we could go forward with a much larger expectation for coal use than we have in the past, that this would carry us into the next century, by which time our solar and nuclear technologies would have developed to the point where they would fulfill our energy needs.

COAL CONSTRAINTS

There are, however, a number of constraints on the vastly increased use of coal as a source of all our fuels. These constraints must be considered and alleviated, if we are going to do what has just been proposed. One of these constraints is the mere fact that we are extracting stored carbon from underground; and by burning it in a fuel cycle of some sort, it is consequently being injected into the atmosphere as carbon dioxide. That this injection of fossil carbon into the atmosphere has been taking place at a rate greater than it is being removed is evidenced in Figure 10.

Here is shown the history of the carbon dioxide level over the last fifteen years, taken at a mountaintop in the middle of the Pacific Ocean. As you can see, roughly one-half of the carbon injected into the atmosphere each winter is removed during the following summer, resulting in a consequent net rise of carbon dioxide in the atmosphere each year. Furthermore, a closer examination of this data indicates that the rate at which it is rising is actually accelerating somewhat over the last fifteen years.

This is indeed a global measurement, since the same kind of result has been obtained from stations at the North and South Poles. The question of what the consequence of this increased carbon dioxide blanket might be for the Earth is another matter. There is, however, one aspect which is very hard to deny - and that is that whatever the mechanisms of carbon dioxide production might add up to and whatever the mechanisms of carbon dioxide removal might turn out to be, they are not matched. The rate of production outstrips the rate of removal. As a consequence, the blanket of carbon dioxide around the globe will increase in thickness. While the meteorologists cannot as yet make any predictions in detail of what the consequences of this increased carbon dioxide blanket are likely to be in terms of changes in the weather, there is one general conclusion which

hardly seems avoidable. This is that the average global temperature must rise, due to the transparency of carbon dioxide to visible radiation and its opaqueness to the resulting infrared, which is generated at the Earth's surface upon conversion of the visible sunlight. The details are yet to be worked out about the weather modifications which this increased blanket is likely to produce. It is a problem of some serious magnitude, and efforts must be made to control it. Here again, chemistry will undoubtedly play an important role.

However, there is still another and more immediate consequence of the increased use of coal, which has been proposed worldwide. As you all know, coal is very poor in hydrogen compared to petroleum or natural gas, and therefore much richer in aromatic components. As an example, we know that when coal is burned in a boiler (or any kind of combustion process, for that matter), a much larger amount of aromatic emissions results from such a combustion process.

A somewhat easier way of expressing the hazards involved in the use of coal is to be found in an examination of the oil which is produced by coal liquifaction (a process which was first used as early as World War I, used again in World War II, and which is now being proposed for renewal). Figure 11 shows an example of one such oil produced from coal, in an experimental plant in the United States. These plants have been designed at a level of about 25,000 tons/day of coal, and it is made clear in this figure that the amount of aromatics that will be in such an oil is very high indeed. In particular, such a plant would produce about ten pounds of benzopyrene per day. When we remember that benzopyrene is one of the most potent carcinogens produced in any combustion process, and that it

is effective at the milligram level in producing lung cancer, we can easily visualize the enormous problems which such an enhanced production of benzopyrene spread into the atmosphere might entail. As a comparison, I have given the analysis of ordinary petroleum, which is not so rich in aromatics compared with this particular coal oil. You can see that there is ten to twenty times as much benzopyrene in the coal oil as there is in petroleum. Of course, the benzopyrene can be removed from this coal oil, and I daresay it will be; but the costs of doing this will affect the uses to which that oil may be expected to be put.

These are only two of the constraints that the environmental problems of coal use will place upon us. The particulate matter that issues from a coal combustion process, and the various kinds of other toxic materials which would issue in the water effluent from a coal liquifaction or gasification plant, are also problems which will have to be considered.

SOLAR RESOURCES

Thus, we are left with the only other alternative which would neither increase the carbon dioxide level nor enhance the carcinogen level (nor produce any other environmental hazard that we are aware of at the moment). This alternative is the use of sunshine, directly as it comes to us, rather than using up the fossilized sunshine which constitutes the petroleum, natural gas, and coal, and which took several hundred million years to produce. We are thus, in a sense, living on our capital account of fossilized sunshine; and the time has now come when we must learn how to live on the annual income of energy from the sun, which is represented by the photosynthetic process.

As an introduction to this, I would like to have you look at a map of the world (Figure 12) showing where the natural photosynthetic carbon fixation actually occurs. In this figure you will see that most of it occurs in the humid tropic regions around the equator: in the Amazon Valley, the Congo Valley, and Southeast Asia. Here the fixation rate is of the order of one kilogram of carbon per square meter per year. However, these regions are relatively fragile, and must be used for more highly important purposes, such as food production. The production of materials, however, ranks a very close second to that of food. What I have contrasted here is the production of materials such as those used in the chemical industry with those needs which are simply the production of energy.

There are other ways in which the energy of the sun might be captured directly, but there is none yet that can use this energy to reduce carbon directly and thus make it useful as a materials resource, which we need for so many other applications. Roughly about ten percent of the fossil hydrocarbon used today is used in the petrochemical industry as a materials source rather than as an energy source, and it is that ten percent materials source toward which we can hopefully look as a possible substitute in direct photosynthetic carbon reduction.

PHOTOSYNTHESIS

We do know a good bit about how the green plant captures the quanta and uses that energy to reduce carbon. The details of that carbon reduction cycle are shown in Figure 13. Here it is clearly seen that the first major product of all green plant photosynthesis is essentially carbohydrate, and most plants store most of the energy so captured in this form (shown in

the upper righthand corner of the circle). In fact, there is a great deal of effort going on throughout the world at this time to find ways to convert that carbohydrate, which is the primary storage product of all green plants, into some form more useful than wood. It is true that one hundred years ago most of the world subsisted on that wood as an energy source. Today, however, our systems are built on more convenient fuel sources (as well as more convenient materials sources), such as liquid hydrocarbons and their relatives. It is this kind of conversion that we are now seeking to make.

Efforts to use carbohydrates stored by plants are perhaps farthest along in the case of the directly fermentable sugars (such as those produced by sugar cane), in which case the sugars can immediately be converted into a liquid fuel by a fermentation step. An example of the growing of sugar cane is shown in Figure 14, which illustrates a cane field being prepared for harvest by a preliminary burn of the dried leaves, which will allow for the entry of the harvesters (either people or machines). This step seems to be universal in the large scale harvesting of sugar cane, and it seems to represent a substantial loss of material. Nevertheless, considerable progress has been made in the development of sugar cane as a source of both fuel alcohol and alcohol that might be used as a starting point for chemical processing.

The essential transformation is shown in Figure 15, in which it is apparent that the conversion of the solid sugar to a liquid form involves a loss or reduction of weight by one-half, without the concomitant loss of any substantial amount of energy. Thus, 180 grams of sugar will produce about 90 grams of alcohol, and it will retain over 90% of the energy content of

the sugar in the process. This alcohol can now be used directly, as a fuel, in an internal combustion engine such as the automobile. All that is required to make the mixture of 95% alcohol and 5% water be useful as a fuel is the insertion of a small heat exchanger between the carburetor (which micronizes the alcohol) and the intake manifold, using the heat of the cooling water from the engine block to vaporize the alcohol. Such engines have actually been built (particularly in Brazil), and are used both for motor cars and for harvesting machinery. In my own experience, such a motor car seems to run just as well, or perhaps even better, than one running on gasoline. The only difference seems to be that the one running on alcohol smells better.

ALCOHOL

A more important use for alcohol, perhaps, is as a raw material or a beginning feedstock for the petrochemical industry. This intercalation is shown in Figure 16, in which the present route to ethylene from naphtha is illustrated, as well as the corresponding route from sugar to ethylene, as the crossing point or point of entry, into the petrochemical industry. The availability of a substantial pool of alcohol in the large sugar growing countries of the world (such as Brazil, and perhaps the Philippines) may very well induce a number of chemical companies to build alcohol crackers to make ethylene, in place of their naphtha crackers from petroleum, which is becoming increasingly unavailable.

Thus, we have a route from the carbohydrate (the primary storage product of most plants) to the hydrocarbon material, which is the raw material of the petrochemical industry. However, this route is limited to those places in which fermentable sugars can be readily and cheaply produced. In many

parts of the world this cannot be done. Instead, the storage product is in the form of cellulose. This would require a preliminary hydrolysis of cellulose to fermentable glucose before the alcohol fermentation could occur. There is a great deal of work going on in the United States and Western Europe (and probably in Northern Europe, as well) toward this end. It is very likely that this work will meet with considerable success, and thus present a new resource for the temperate regions of the world in the form of the ability of these regions to produce cellulosic materials, as a starting point for the kind of petrochemical industry to which we have become accustomed. However, those plants, as a general rule, which are very competent carbohydrate producers also require the kind of land that can also be used for food production; therefore, the competition between food production and materials production by these routes might begin. This seems to me to be an undesirable competition, in view of the food requirements of the world. Therefore, we have set about to find other ways than this one to fill the need for hydrocarbon.

HYDROCARBONS

Let me remind you of the photosynthetic carbon cycle, which I showed you in Figure 13. While it is true, as shown in that figure, that most of the plants with which we are normally familiar store their solar energy in the form of reduced carbon (carbohydrate), there do exist a number of plants which can store this energy, in substantial amounts, in the form of a more fully reduced carbon (such as hydrocarbon). The ones that are most commonly known to you as a commercial crop are the rubber plants of the world. There is one major rubber plant, and one minor one, which is rapidly rising in importance. The major one, of course, is Hevea brasiliensis, for which all the plantations exist on a large scale in Southeast Asia, primarily

in Malaysia and Indonesia. Figure 17 is a picture of a tapped rubber tree in Brazil, but they look very much the same all over the world. The latex that you see running out of the tap, and along the bark into the cup, is an emulsion of hydrocarbon in water consisting of about one-third hydrocarbon. The molecular weight of that hydrocarbon is very large (approximately two million), so when the emulsion is coagulated and the hydrocarbon settles out as a coagulum, the hydrocarbon separated from the water is an elastomer. That is, it is rubber.

There are many other plants belonging to the same family (the Euphorbiaceae family) that Hevea belongs to, which also produce latex. In many cases this latex consists of an emulsion of a hydrocarbon in water in which the molecular weight of the hydrocarbon is much smaller - of the order of ten to twenty thousand. In this case, when the oil and water are separated from the emulsion, the resultant hydrocarbon that remains is not big enough to be a solid rubbery material, but rather is a liquid oily material consisting of a very complex mixture, mainly of reduced carbon atoms. These plants, however, tend to grow for the most part in the humid tropics, and we saw many of them as we moved down the Amazon in our search for oil producing plants.

However, there are a number of such plants, both in this family and in other families, which grow in the arid regions of the Earth. An example of such a plant that produces a large hydrocarbon, rubbery in character, is the well known guayule plant. Guayule is a member of the Compositae family, and grows in the deserts of Northern Mexico and the Southwestern United States, as is shown in Figure 18. If plants with this behavior (that is, plants which could be grown in the arid and the semi-arid parts

of the world) could be found which produce lighter or lower molecular weight hydrocarbons, then we might have a direct source of photosynthetically produced hydrocarbons which would not be in competition with the land that may ultimately be required for food production.

Figure 19 shows a map of the land areas of the Earth in which the semi-arid regions and savannas are illustrated and distributed, covering both the Northern and Southern Hemispheres, and including the Southwestern part of the United States, Southern Africa, Australia, and South America. These lands are presently relatively unproductive, either for food or for any other use. We hope to be able to find plants that can be adapted to that kind of a growth environment, which will produce hydrocarbon directly.

In fact, an exploration of such parts of the world has already begun. In Southern California we have found a number of members of the genus Euphorbia which grow wild and which are prolific producers of latex. Similarly, along the Southern Coast of Puerto Rico, we have seen another group of plants growing, also of the Euphorbia genus. Figure 20-A shows one of them, Euphorbia trigona; and when we pierced it with a knife, the flow of latex was evident. The South Coast of Puerto Rico is a relatively arid region, as shown in Figure 20-B, and might be considered fairly representative of the larger semi-arid regions of the world shown in the previous map.

Many other plants of the same genus grow in similar circumstances.

Euphorbia tirucalli, the well-known African milkbush, grows very well in Southern California, and could very likely be developed as a latex-producing tree as well. However, being a Northern Californian, I was seeking plants which might be grown in the somewhat harsher climate farther North. In fact, we found a member of the genus Euphorbia that grows very well in Northern

California, and a picture of it is shown in Figure 21. It is known as Euphorbia lathyrus. We have indeed begun to determine the growth rate of this plant. The Euphorbia lathyrus can be grown annually from seed and harvested in much the same way that sugar cane is harvested, as opposed to the trees (Euphorbias trigona and tirucalli) discussed earlier, in which the oil would have to be harvested by a tapping (or at the very least, a mowing) operation.

The growth data on the Euphorbia lathyrus is shown in Figure 22, and it indicates that we can expect to obtain with confidence not less than six barrels of oil/acre/year. This would be about fifteen barrels/hectare/year. This is, of course, without any agronomic care or selection of the plant at all. It comes from a wild seed, and this is the first planting of it.

Bearing in mind that we are seeking, in the first instance, a replacement for the petrochemical feedstocks rather than solely a fuel use, we must now learn much more about the chemical composition of the hydrocarbon mixtures of these Euphorbias that I have just described. We have begun to do this, and Figure 23 shows an analysis of the sterol contents of a variety of Euphorbias. In Table 1, the relative amounts of open-chain polyisoprene, here designated as rubber, are compared with the sterol content. The relative amounts of sterols are also shown in a wider selection, which also includes an analysis of guayule and Hevea. Most of these latexes also contain a number of terpenes as well, but we have not analyzed for them.

Finally, in Figure 24, I want to show a comparison of the molecular weights of the rubber component of a genuine rubber plant such as Hevea. In Hevea, the molecular weight distribution is shown to be bimodal, with a peak at half a million and another one at two million, as compared to a similar gel

Preliminary results
7/16/77

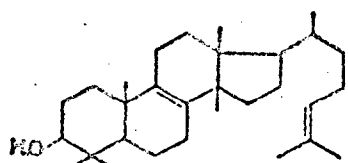
TABLE: 1 STEROLS AND POLYISOPRENES FROM EUPHORBIACEAE LATEX

SPECIES	% of Dry Latex (w/w) ¹		Ratio (R/S)	RELATIVE AMOUNT OF STEROLS											
	Rubber	Sterol		A	B	C	D	E	F	G	H	I	J		
<i>Euphorbia aphylla</i>					.37		.10	.82	1.0	.46					
<i>Euphorbia arbuscula</i>				1.0	.19										
<i>Euphorbia balsamifera</i>	4	93	0.04												1.0
<i>Euphorbia bupleurifolia</i>															
<i>Euphorbia characias</i>							.13	1.0	.68	.27					
<i>Euphorbia coerulescens</i>	1	75	0.01	1.0	.10	.20									
<i>Euphorbia cylindrifolia</i>				1.0	.25			.50							
<i>Euphorbia globosa</i>										.30					1.0
<i>Euphorbia ingens</i>	8	78	0.10												
<i>Euphorbia lathyris</i>	3	50	0.06	.12			.80	.50	.30	1.0					
<i>Euphorbia marlothii</i>									.41				.32	1.0	
<i>Euphorbia misera</i>				.69	.32		.66		1.0						
<i>Euphorbia obtusifolia</i>				.05				1.0	1.0	.50					
<i>Euphorbia sp. (American)</i>				1.0	.34										
<i>Euphorbia stenoclada</i>				1.0	.16							.29	.17		
<i>Euphorbia tirucalli</i>	1	50	0.02	1.0	.10										
<i>Euphorbia trigona</i>	1.5	76	0.02	1.0						.61					
<i>Elaeophorbia drupifera</i>				1.0	.16	.20									
<i>Acyras sapote</i>	14	66	0.21									1.0	.20		
<i>Asclepias sp. (USA)</i>	(12)	(72)	0.17									1.0	.20		
<i>Asclepias sp. (Brazil)</i>	3.5	31	0.11									1.0	.20		
Guayule				1.0		.20		.35							
<i>Hevea brasiliensis</i> ²	87	1	87.0												
<i>Synadenium grantii</i>															1.0

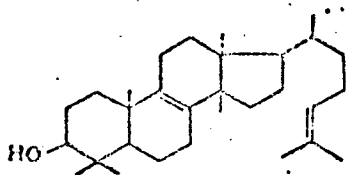
KEY: A Euphol B Tirucallol C Euphorbol D Lanosterol E Lanosterol isomer F Cycloartenol
G 24-Methylene cycloartanol H α -Amyrin I β -Amyrin J Other pentacyclics

1 These numbers were estimated on the basis of NMR spectra (60 M Hz, $CDCl_3$) of the benzene and acetone extracts.

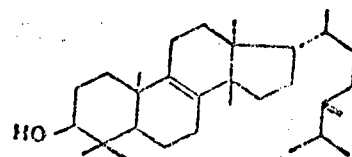
2 Identified sterols are β -sitosterol, fucosterol and stigmasterol (1.0, .50 and .25 respectively).



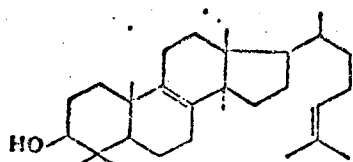
A Euphol



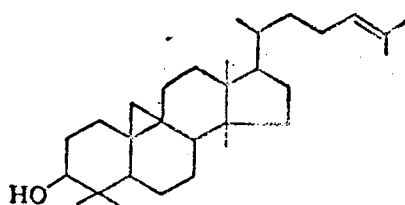
B Tirucalol



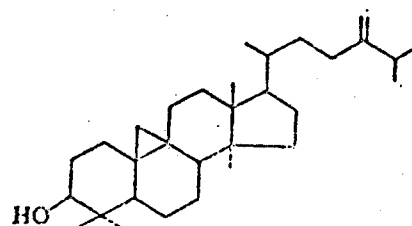
C Euphorbol



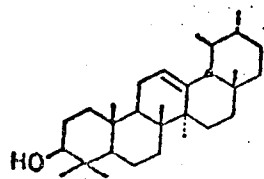
D Lanosterol



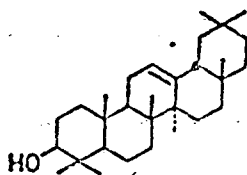
F Cycloartenol



G 24-Methylene cycloartenol



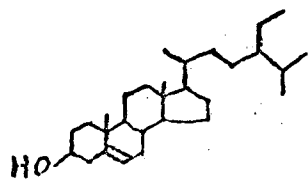
H α -AMYRINE



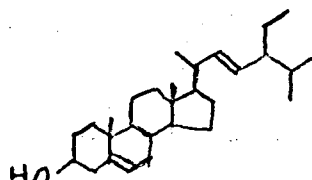
I β -AMYRINE

E Lanosterol isomer

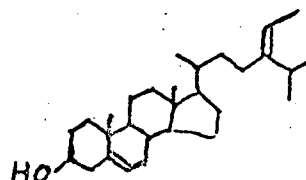
J Other Pentacyclics



β -Sitosterol



Stigmasterol



Fucosterol

Key to Table 1.

permeation chromatogram on the low molecular weight of hydrocarbons obtained from another Euphorbia. Here you see that the peak is somewhere in the vicinity of twenty thousand, and its significance beyond that is moot. The only thing we can say with confidence about this curve is that the molecular weight distribution in most of the other Euphorbias (of the open-chain polyisoprenes) is considerably smaller, and they peak somewhere around the ten thousand molecular weight range.

Now, the question is almost certain to be in your minds as to how much, or at what costs (both in money and in land), can we obtain this material. Unfortunately, the experiments of planting and measuring are still underway. We have planted an annual, which I have mentioned earlier (Euphorbia lathyrus), and this plant is giving us at least a clue as to the amount of oil we can expect from this particular Euphorbia. We have also put in a planting of Euphorbia tirucalli, which will grow to be a tree, and of Euphorbia trigona, which will also be a tree, or bush-like plant. The harvesting time for these two is considerably longer, and therefore I cannot really give you any substantial information yet about the yields we may expect from these tree-like plants.

However, using what data we have on the Euphorbia lathyrus, the annual plant, we do come out with some yield numbers which I have already given you, and also with some cost numbers, which are very rough, to be sure. But it looks as though we could make this complex mixture of hydrocarbons (as obtained from Euphorbia lathyrus or the other Euphorbias) at a price of about \$10.00 to \$15.00 per barrel of oil in the field; and another \$10.00 per barrel would be required to take the oil from the plant and put it in the barrel. So we are talking about a price of crude oil, a

mixture of hydrocarbons, of the order of \$20.00 per barrel. This price is not far from our present one of \$13.00 or \$14.00, and we know that this present price, for crude oil from the ground, will rise. Thus, it seems to me to be entirely possible that we may indeed be able to return to a current income account for our hydrocarbons needed for materials, as a resource. It may even be possible in some cases to use them as a fuel, as well. And this, in turn, will help solve the problems we indicated earlier which are limiting our productivity, both in agriculture (2) and in materials for the welfare of mankind.

REFERENCES

1. Thomas McKeown, The Modern Rise of Population, Academic Press, New York (1976).
2. James A. Bassham, Science 197, 630-638 (1977).

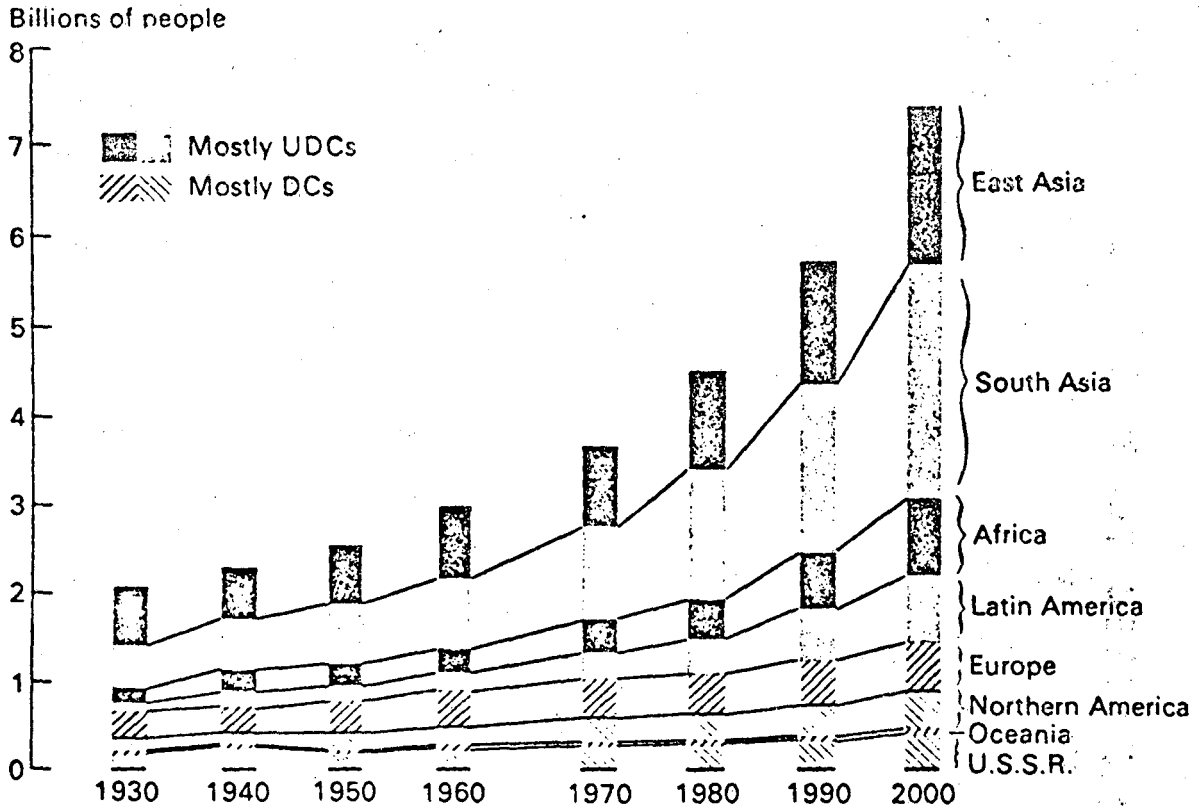
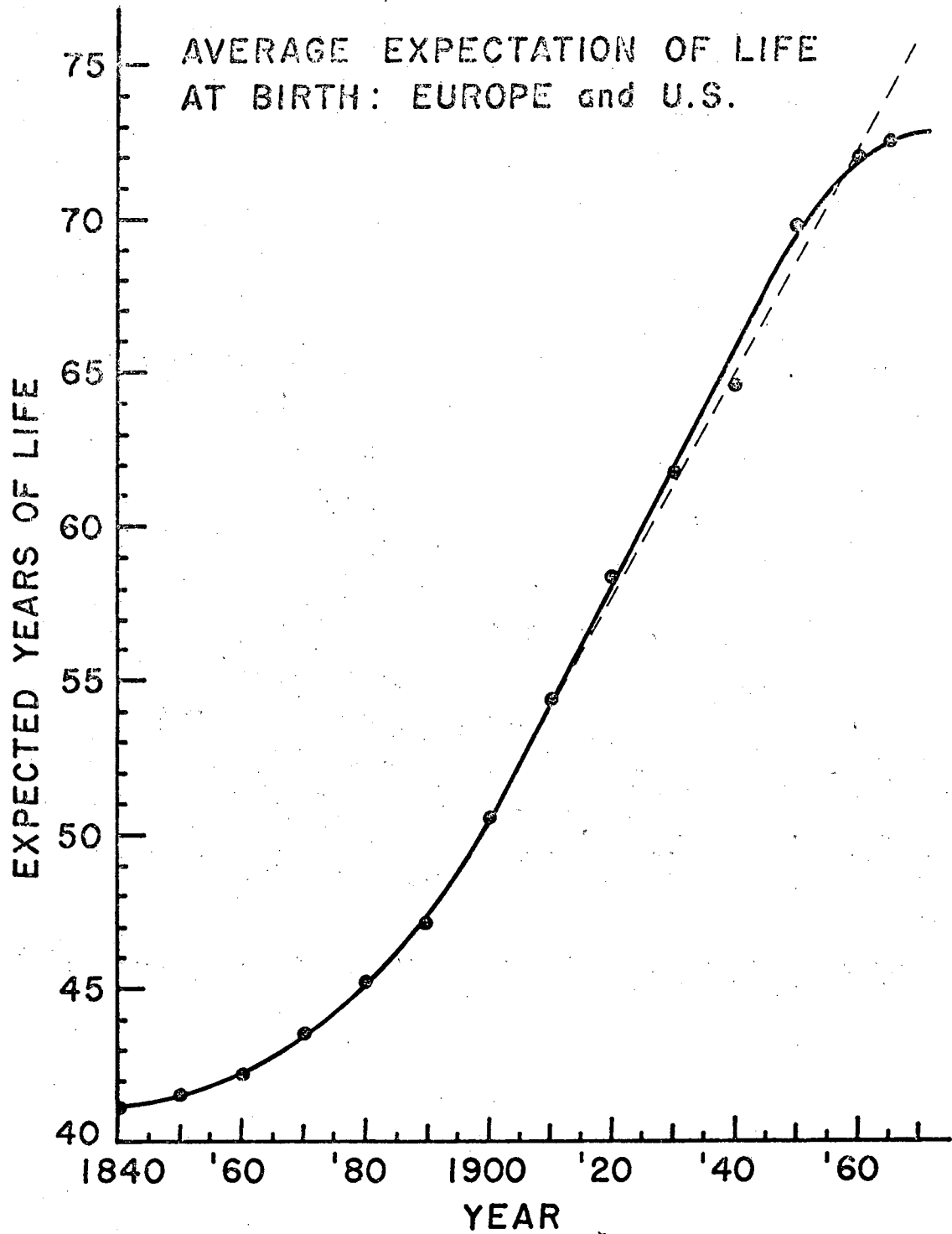


FIGURE 3-10

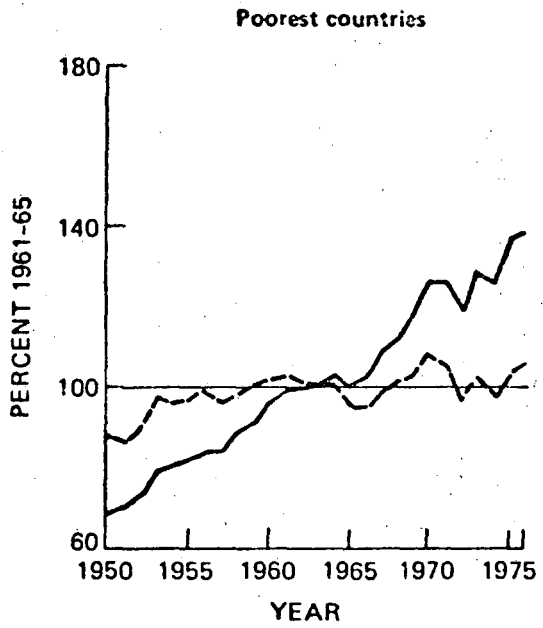
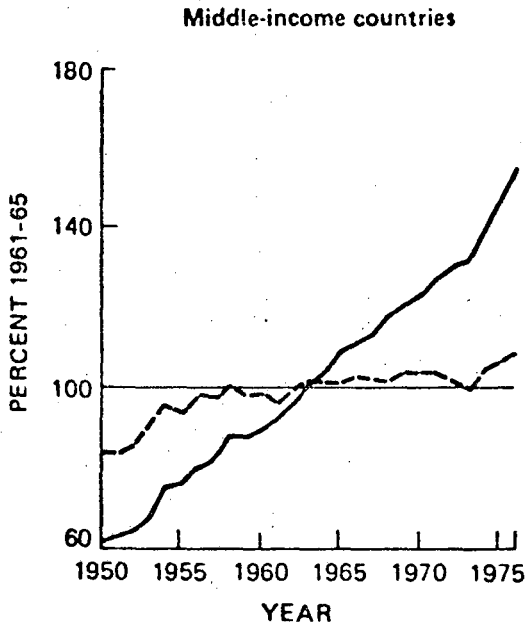
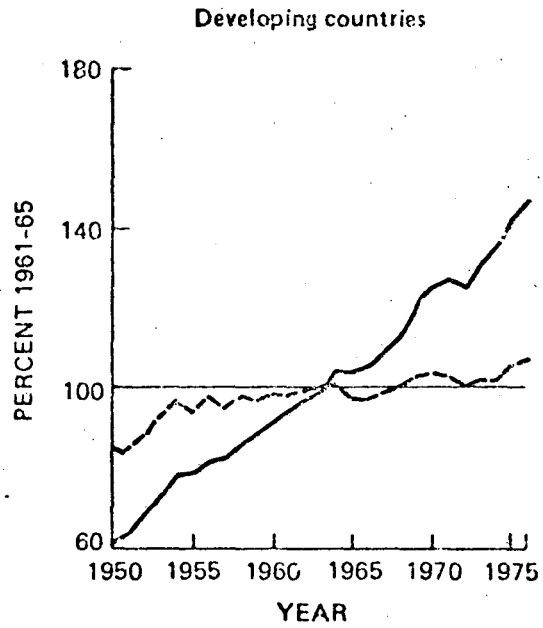
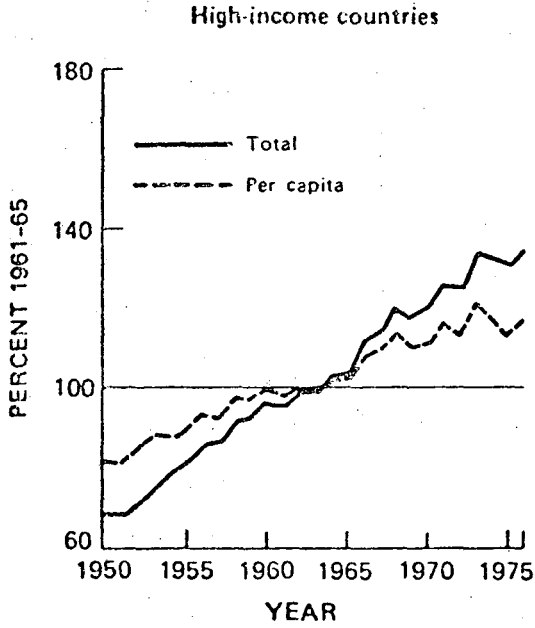
Projected growth of world population, based on the United Nations "constant fertility" projection. [After *Population Bulletin*, vol. 21, no. 4.]

XBL 778-2638



(From Table V.2, p. III, Pop. Trends, Vol. I, U.N., 1973)

XBL7512-8796



Food production indices: total and per capita, 1950-1976 (1961-65 = 100). From U.S. Department of Agriculture, Economic Research Service (1977).

XBL 778-2599

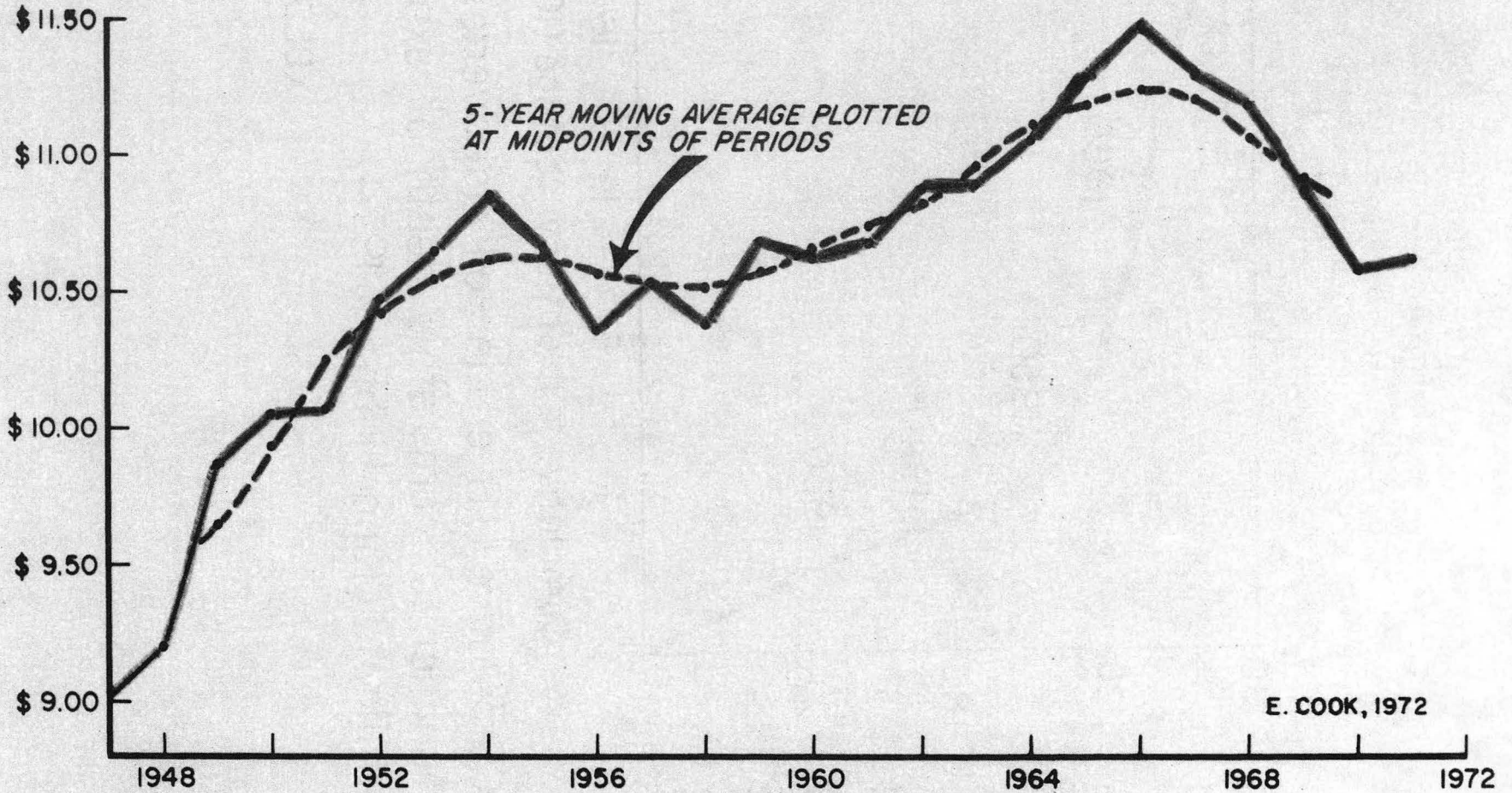
WORLD ENERGY CONSUMPTION AND POPULATION BY MAJOR REGIONS, 1950, 1960, 1970

REGION	1950		1960		1970	
	POPULATION (MILLION)	Per capita CONSUMPTION 10 ⁶ BTU	POPULATION (MILLION)	Per capita CONSUMPTION 10 ⁶ BTU	POPULATION (MILLION)	Per capita CONSUMPTION 10 ⁶ BTU
NORTH AMERICA	166.1	221.9	198.7	245.1	226.2	329.3
CANADA	13.7	197.6	17.9	217.0	21.4	328.9
UNITED STATES	152.3	224.3	180.7	248.0	204.8	329.3
WESTERN EUROPE	302.4	57.8	326.5	79.8	350.4	134.3
OCEANIA	12.2	73.0	15.4	90.8	19.2	127.7
LATIN AMERICA	161.9	14.8	212.4	23.3	282.0	32.4
ASIA (EXCL.COMM.)	805.4	4.7	970.6	8.5	1231.3	16.9
JAPAN	82.9	21.0	93.2	39.4	103.4	208.9
OTHER ASIA	722.5	2.9	877.4	5.2	1127.9	8.5
AFRICA	217.0	6.0	276.0	7.9	349.5	10.5
USSR & COMM.EAST.EUR.	269.8	47.6	312.9	83.0	348.4	128.5
U.S.S.R.	180.0	46.8	214.0	83.5	242.8	131.8
EASTERN EUROPE	89.7	49.2	98.5	82.0	105.6	120.9
COMMUNIST ASIA	509.8	2.2	677.5	9.7	795.6	14.2
WORLD	2504.5	30.7	2989.9	41.5	3608.6	59.4

FROM: ENERGY IN THE 1980'S (ROYAL SOCIETY OF LONDON)

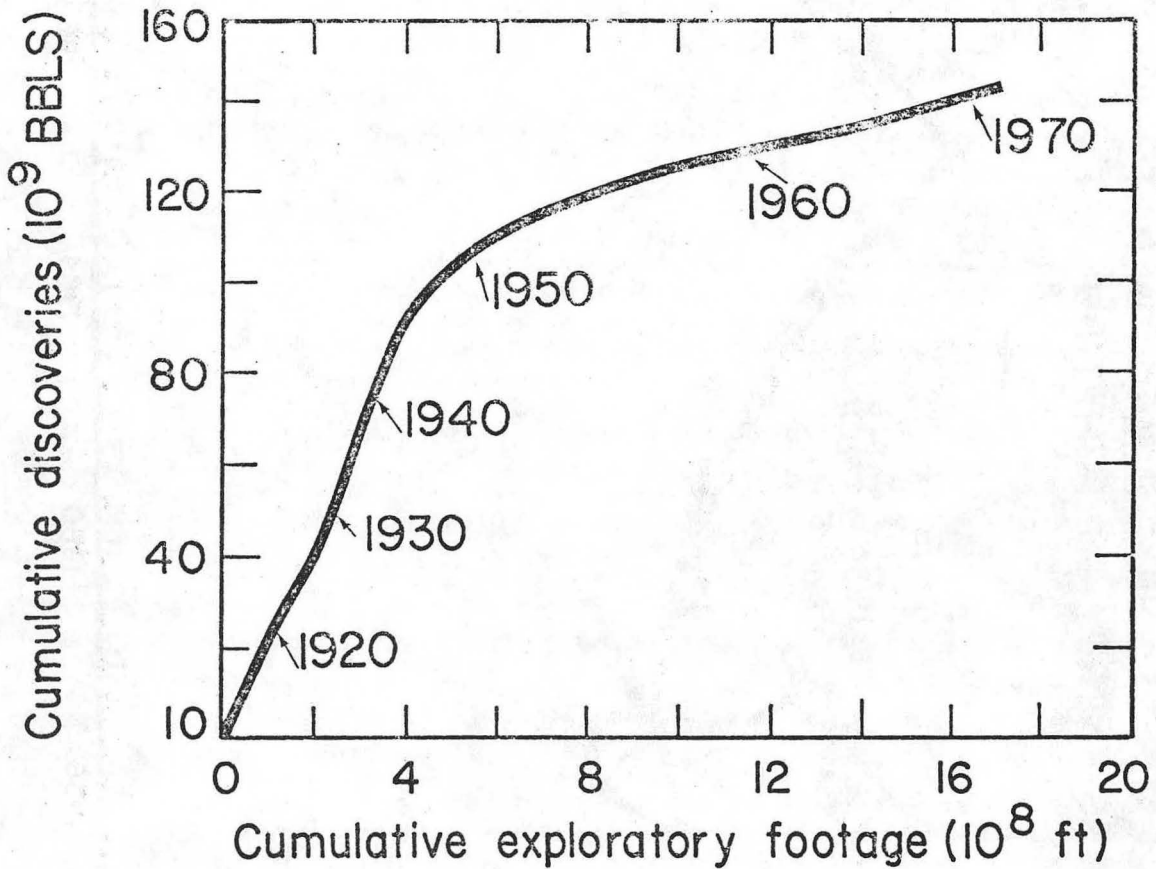
XBL 776-4477

1958 DOLLARS OF GNP PER MILLION BTU
GROSS ENERGY CONSUMPTION



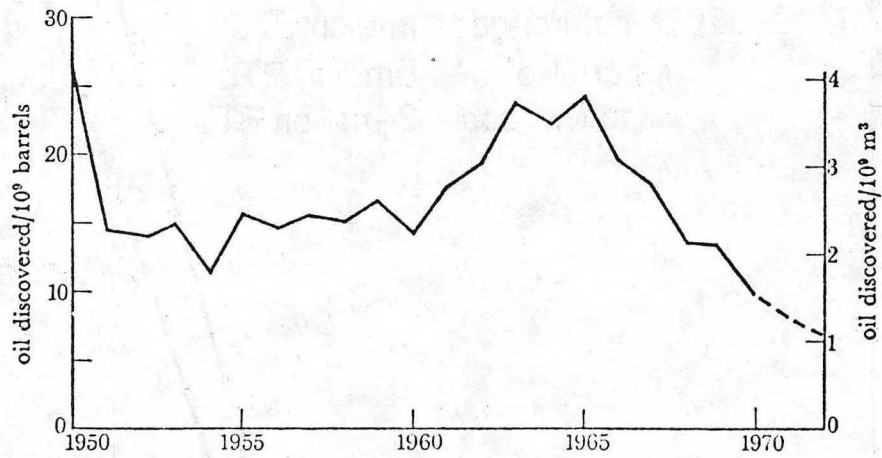
0 0 0 0 4 8 0 723-4 0 2

Fig. 5 Dollars of GNP/Million BTU, Gross Energy Consumption



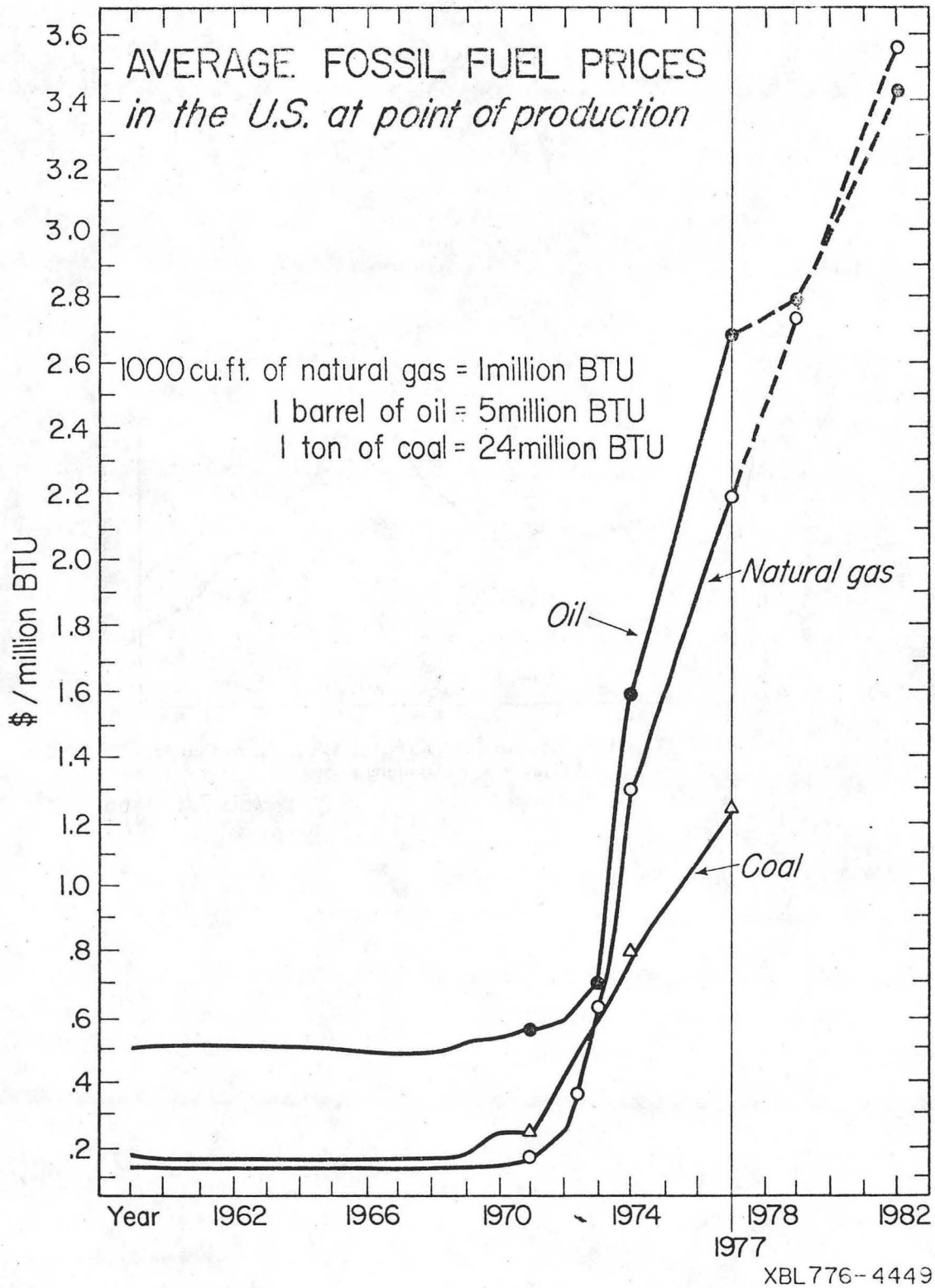
Cumulative U.S. crude-oil discoveries as a function of cumulative depth of exploratory drilling. (King Hubbert, 1974)

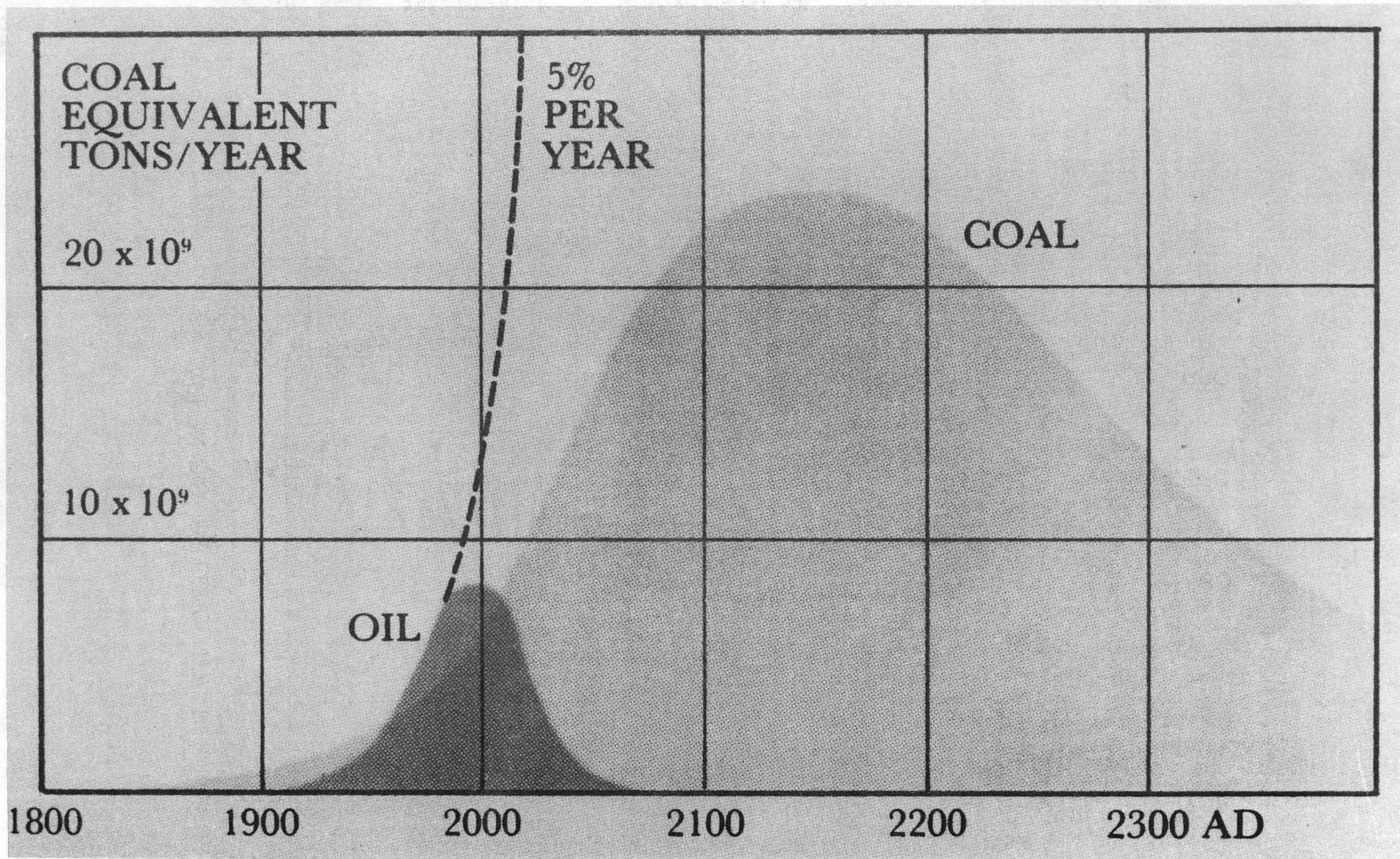
XBL 776-4467



World oil discoveries, excluding U.S.S.R., Eastern Europe and China - 5-year running mean.

XBL 776-4465

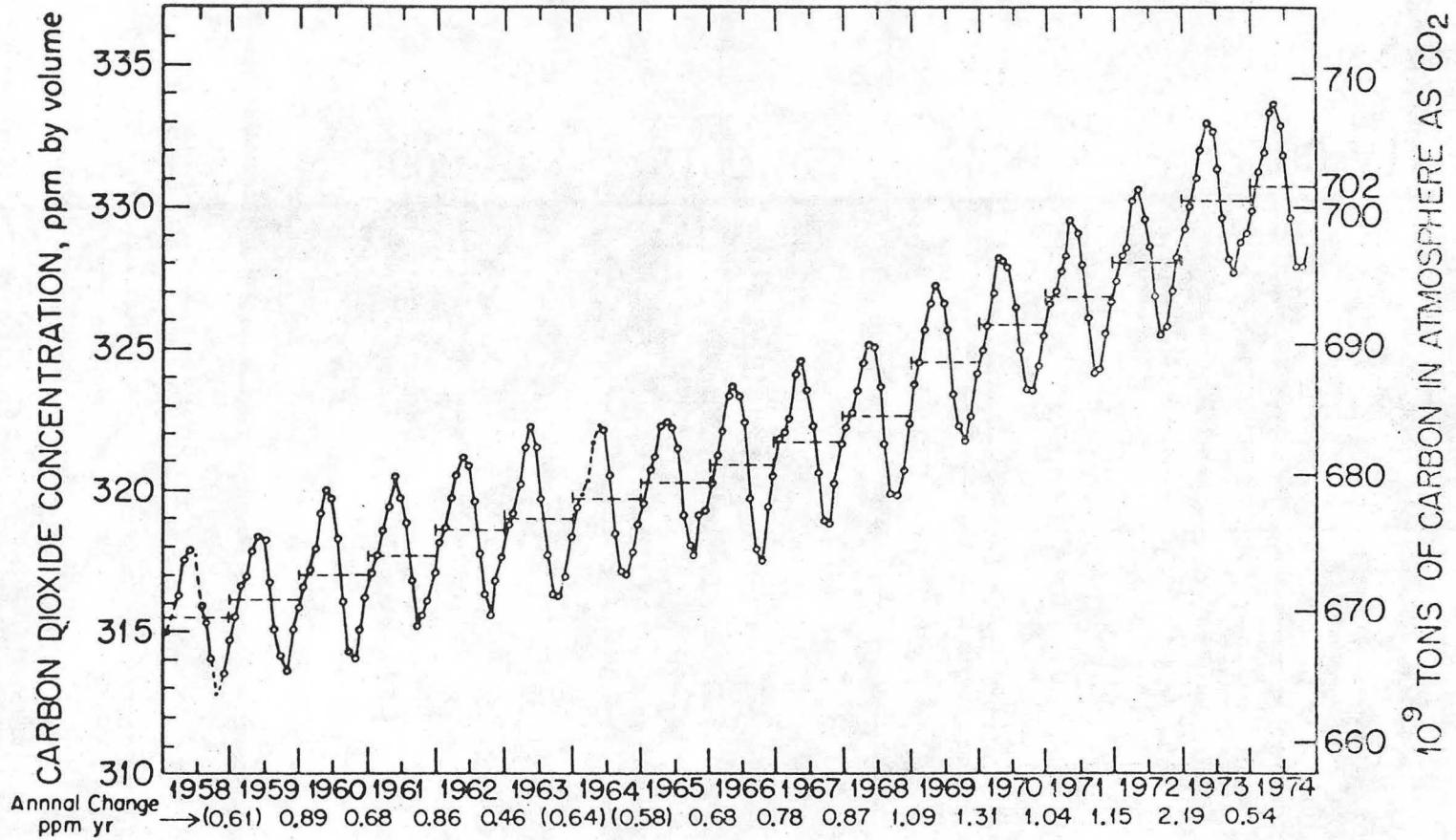




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XBB 778-7577

Fig. 9 Oil and Coal Use Cycles



Atmospheric carbon dioxide concentration at Mauna Loa Observatory, 2500 m (From Keeling)

XBL 772 - 4161

POTENTIAL CARCINOGEN PRODUCTION
IN COAL OIL PLANT

(25,000 TONS / DAY OF COAL)

POLYCYCLIC AROMATICS - - - 200,000 lbs/day

BaP - - - - - 10 lbs/day

BaP concentration

PETROLEUM - - - - - 1-5 ppm

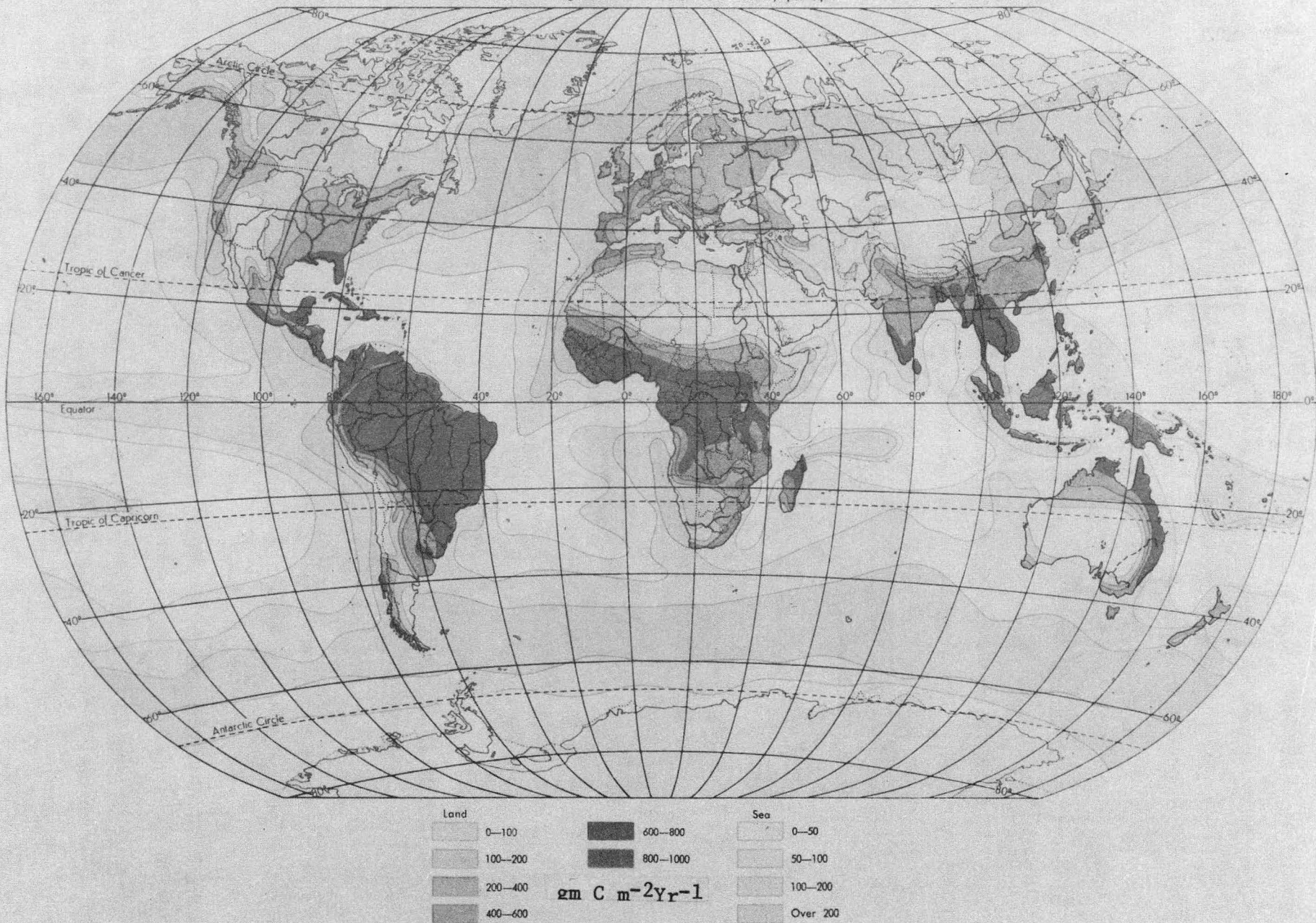
COAL OIL - - - - - 10-100 ppm

XBL 773-4287

-28-

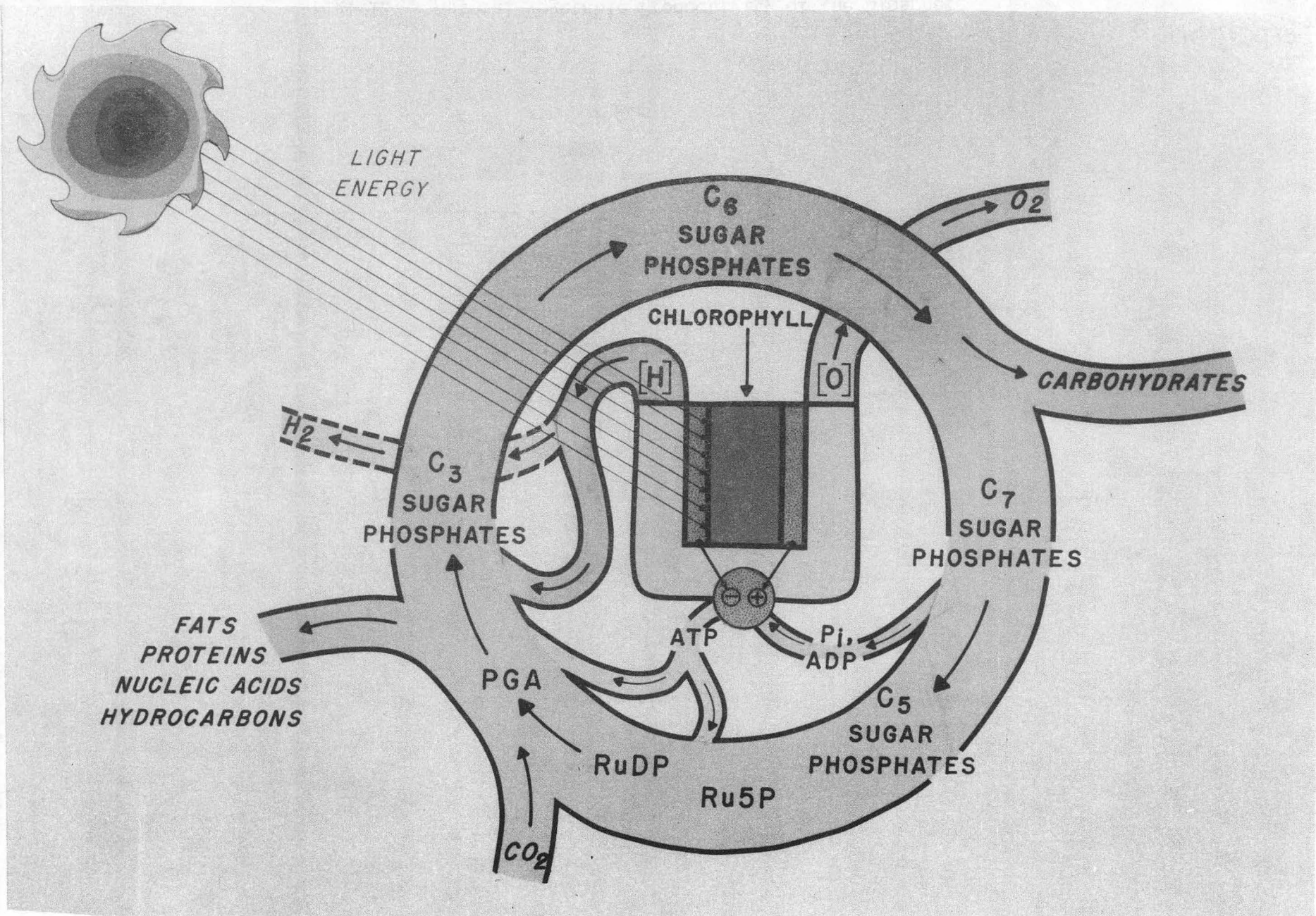
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NATURAL VEGETABLE PRODUCTIVITY OF BIOSPHERE (After Gessner 1959 and Lieth 1965)
 Expressed in grams of carbon assimilated annually per sq.m



00004807-29-06

Fig. 12 Natural Vegetable Productivity of the Biosphere



CBB 740-6756

Fig. 13 Photosynthetic Carbon Reduction Cycle

0 0 0 0 4 8 0 7 - 3 1 - 0 7

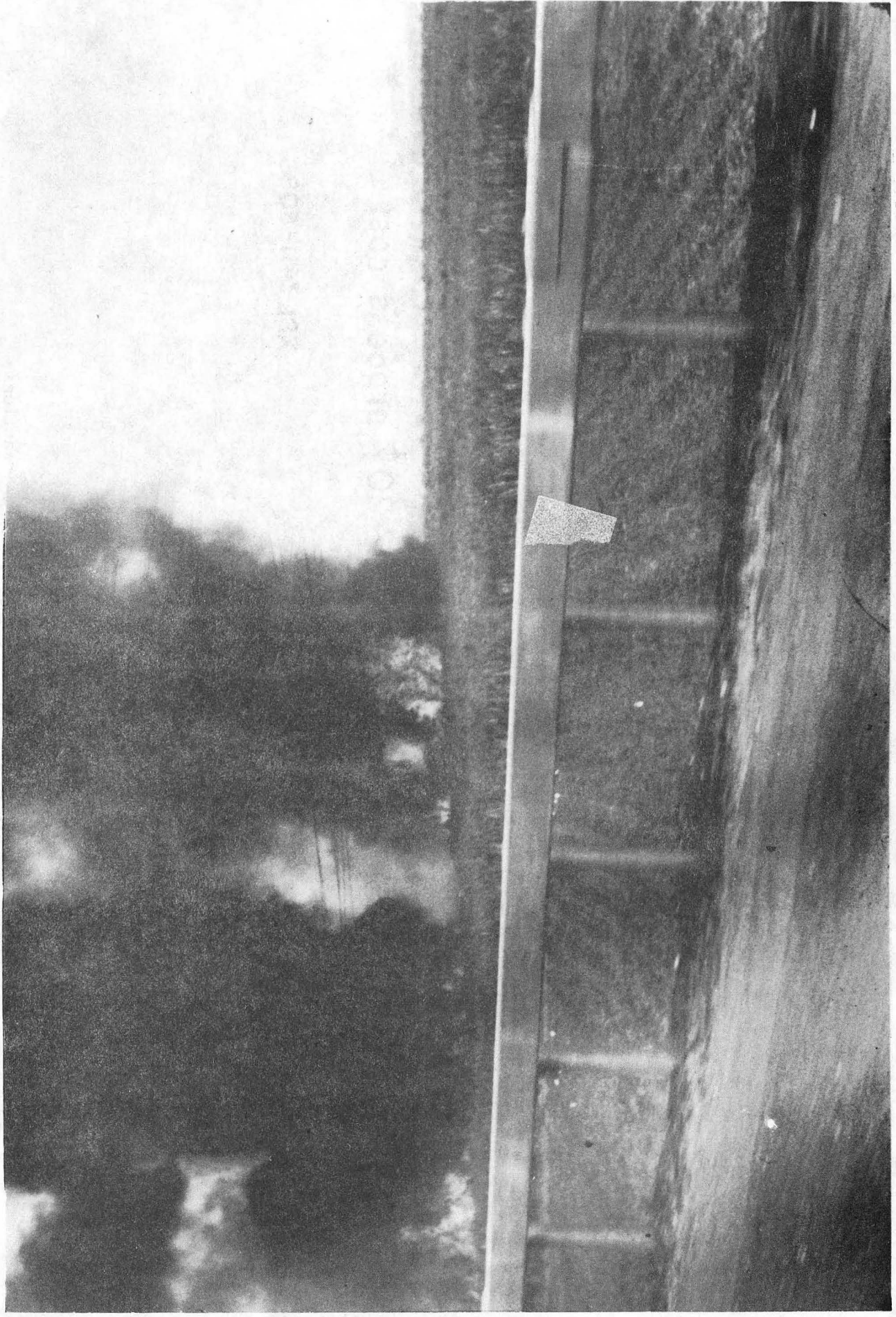
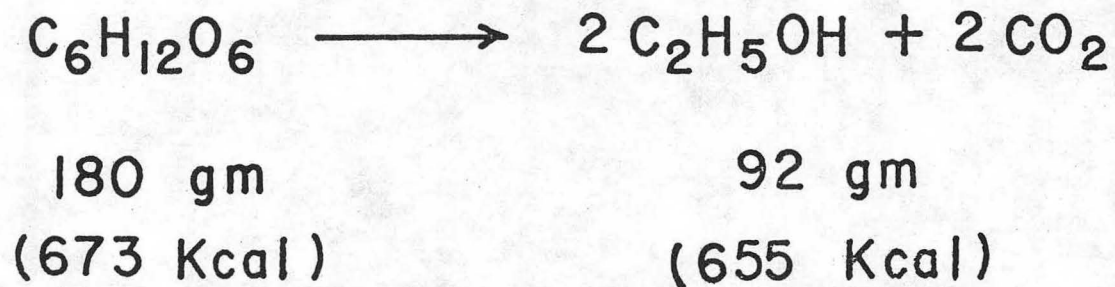


Fig. 14 Sugar Burn, Puerto Rico

CBB 778-7588

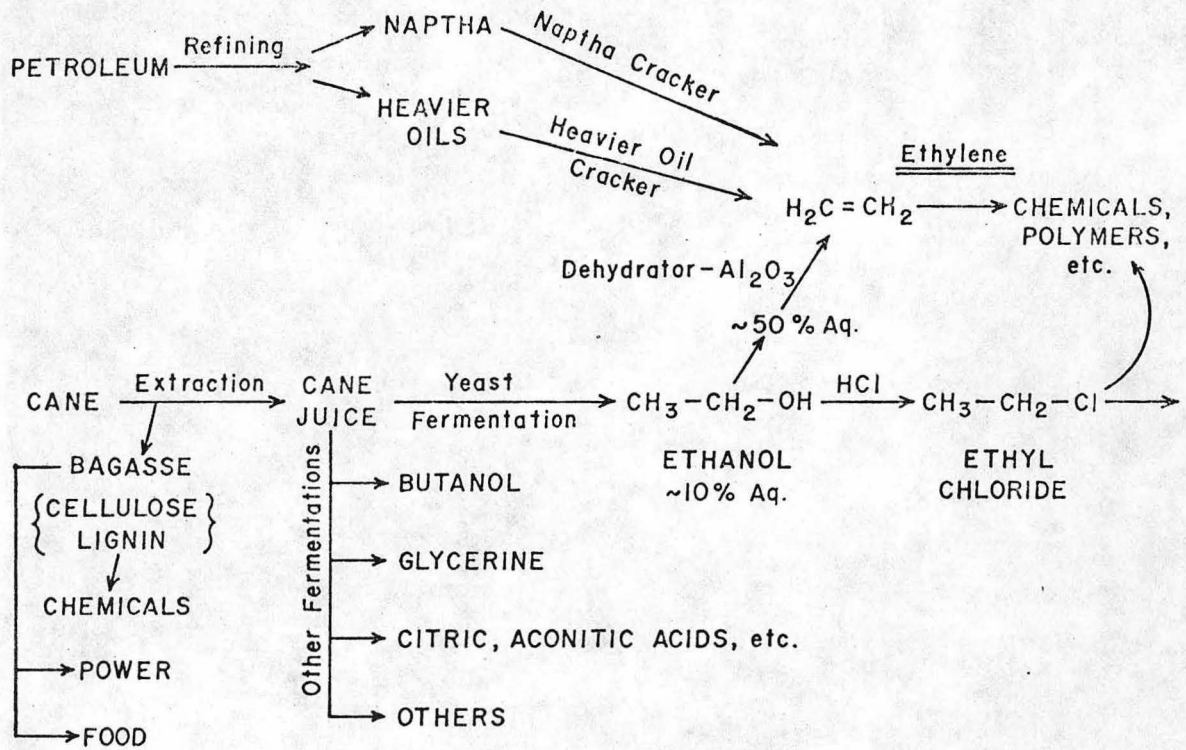


12.88 lbs \longrightarrow 1 gal. (84,356 B.T.U.)

Cost / gal. = raw material + ~20¢ process cost

-32-

XBL7411-8086



RENEWABLE RESOURCE FOR CHEMICALS

XBL754-5207

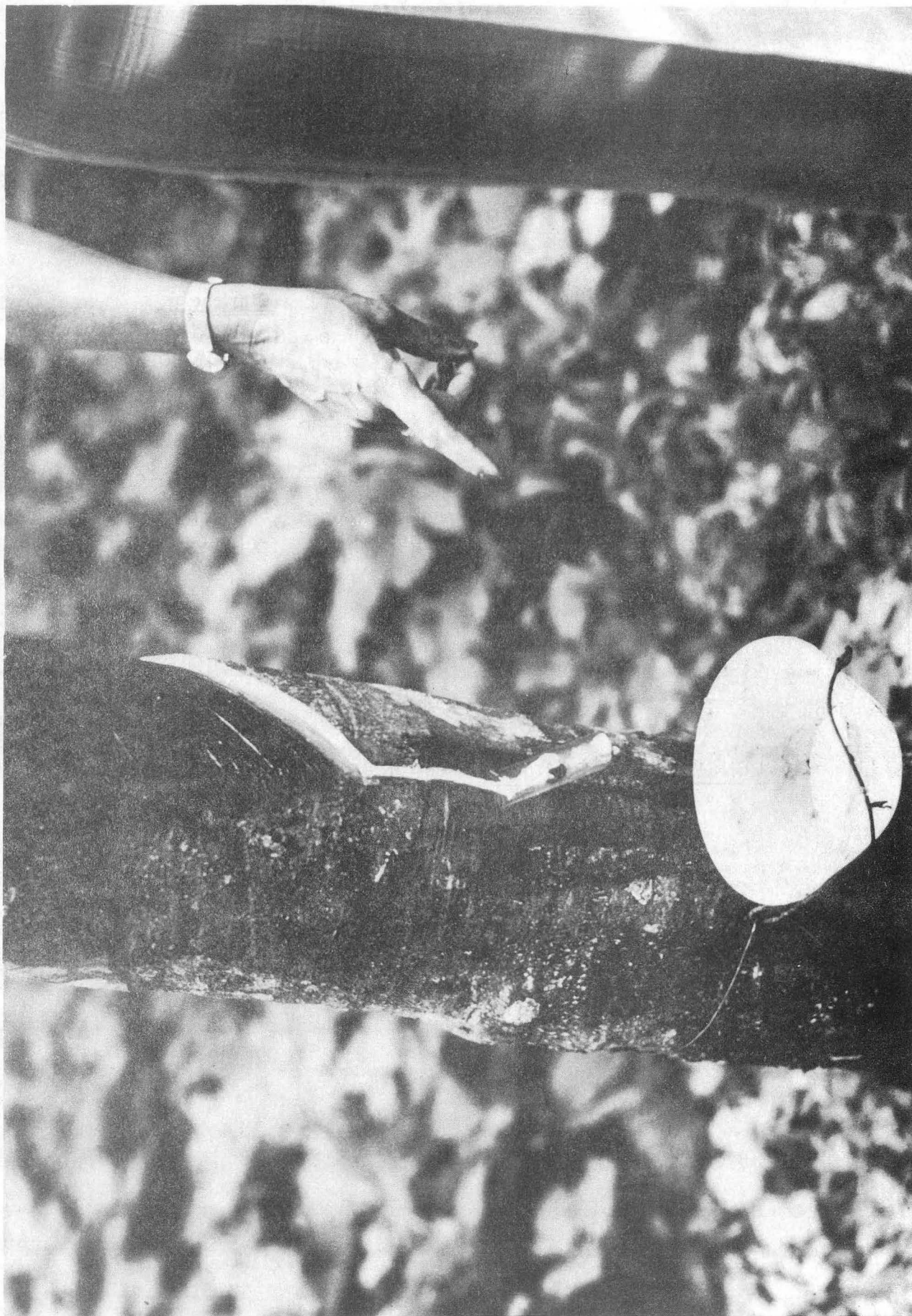


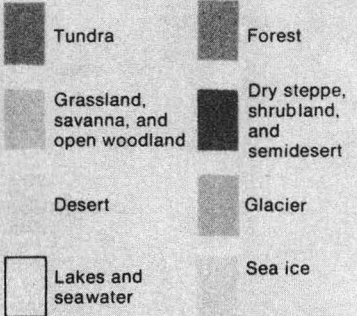
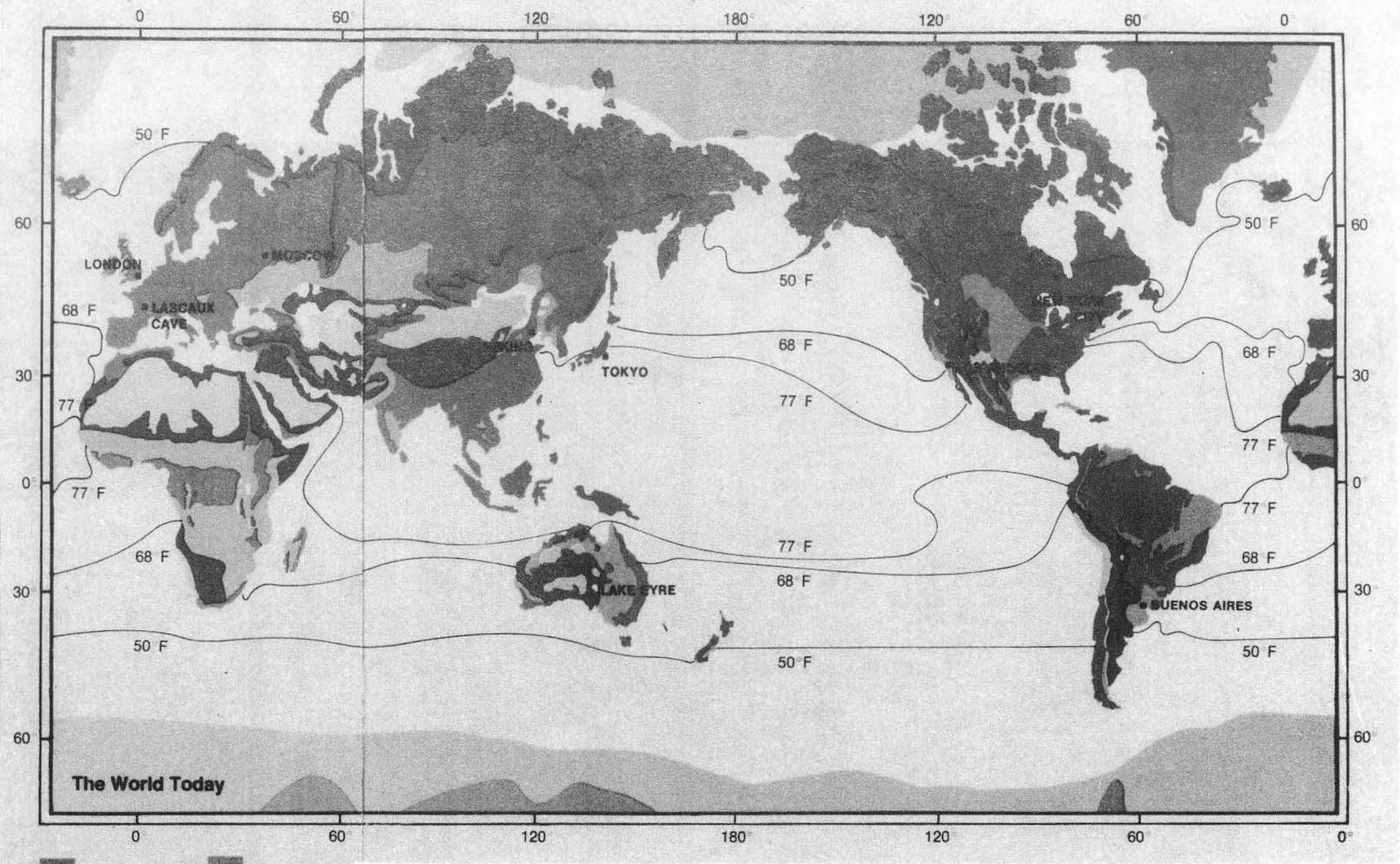
Fig. 17 Rubber Tap, Brazil

CBB 757-5366



CBB 778-7592

Fig. 18 Guayule, Saltillo, Mexico



Conditions pertain to summer in the Northern Hemisphere. Vegetative zones refer to potential vegetation without human interference.

CBB 765-4535

Fig. 19 Global Map Showing Semi-Arid and Savanna Regions

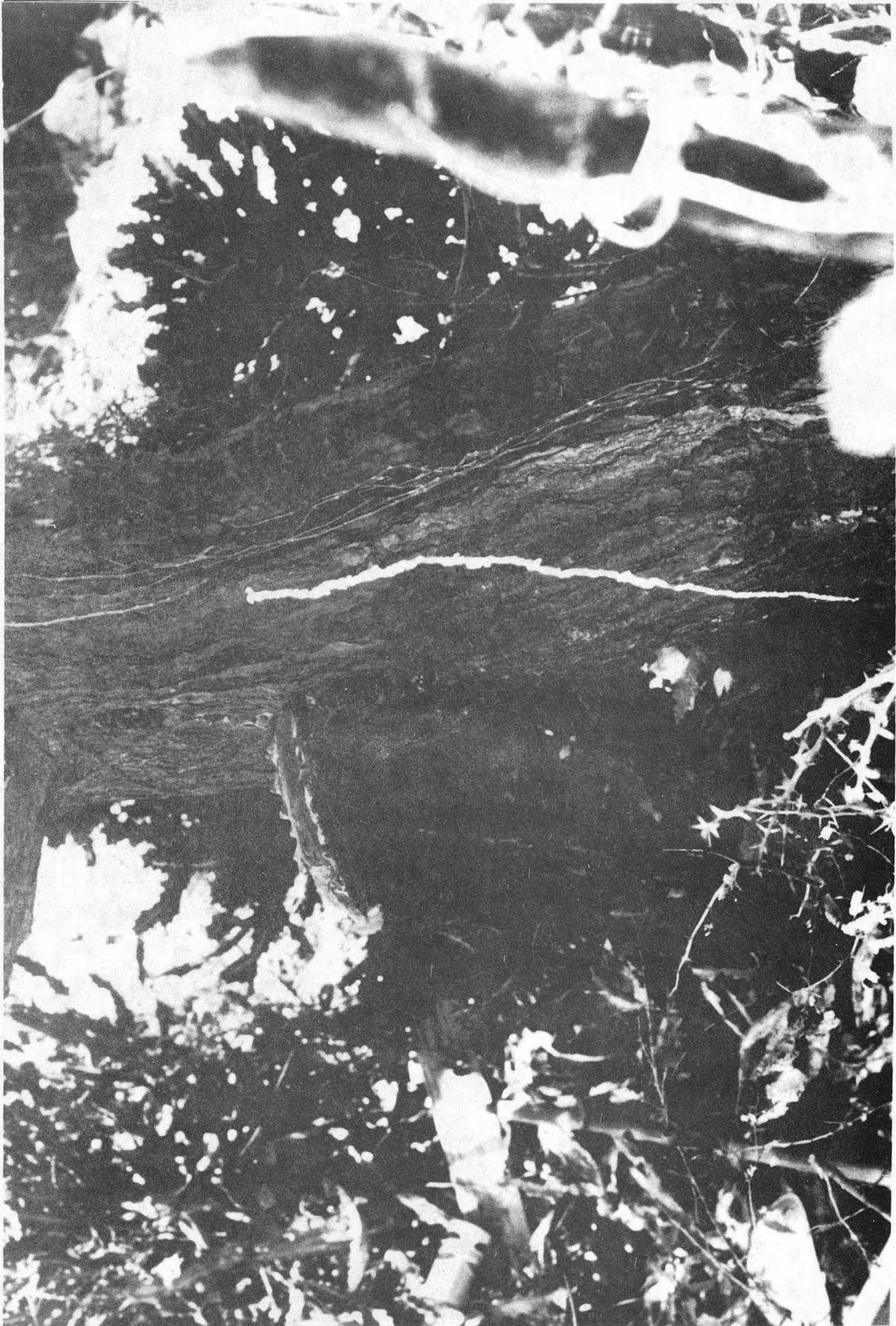
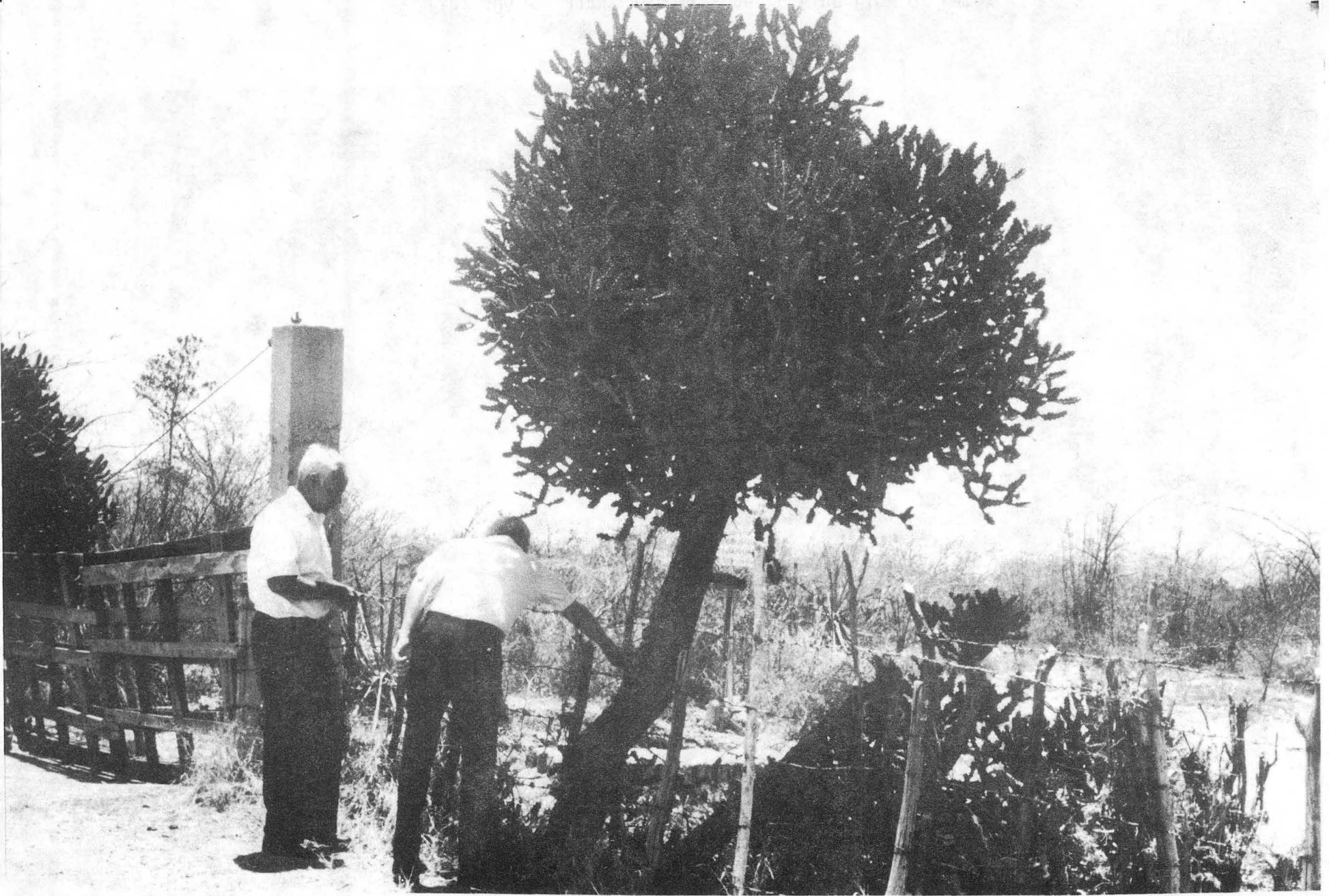
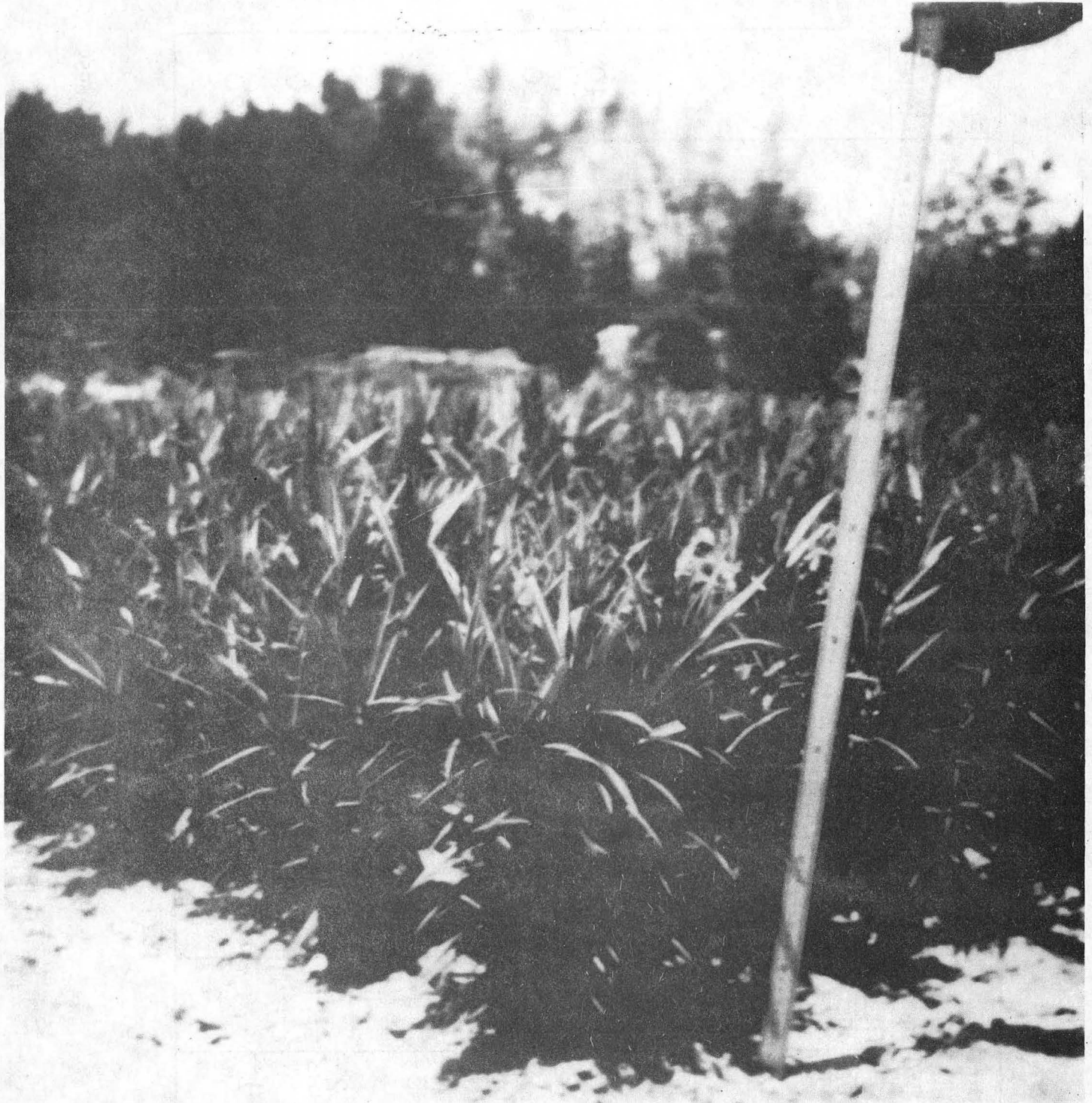


Fig. 20A Euphorbia Trigona Showing Flow of Latex



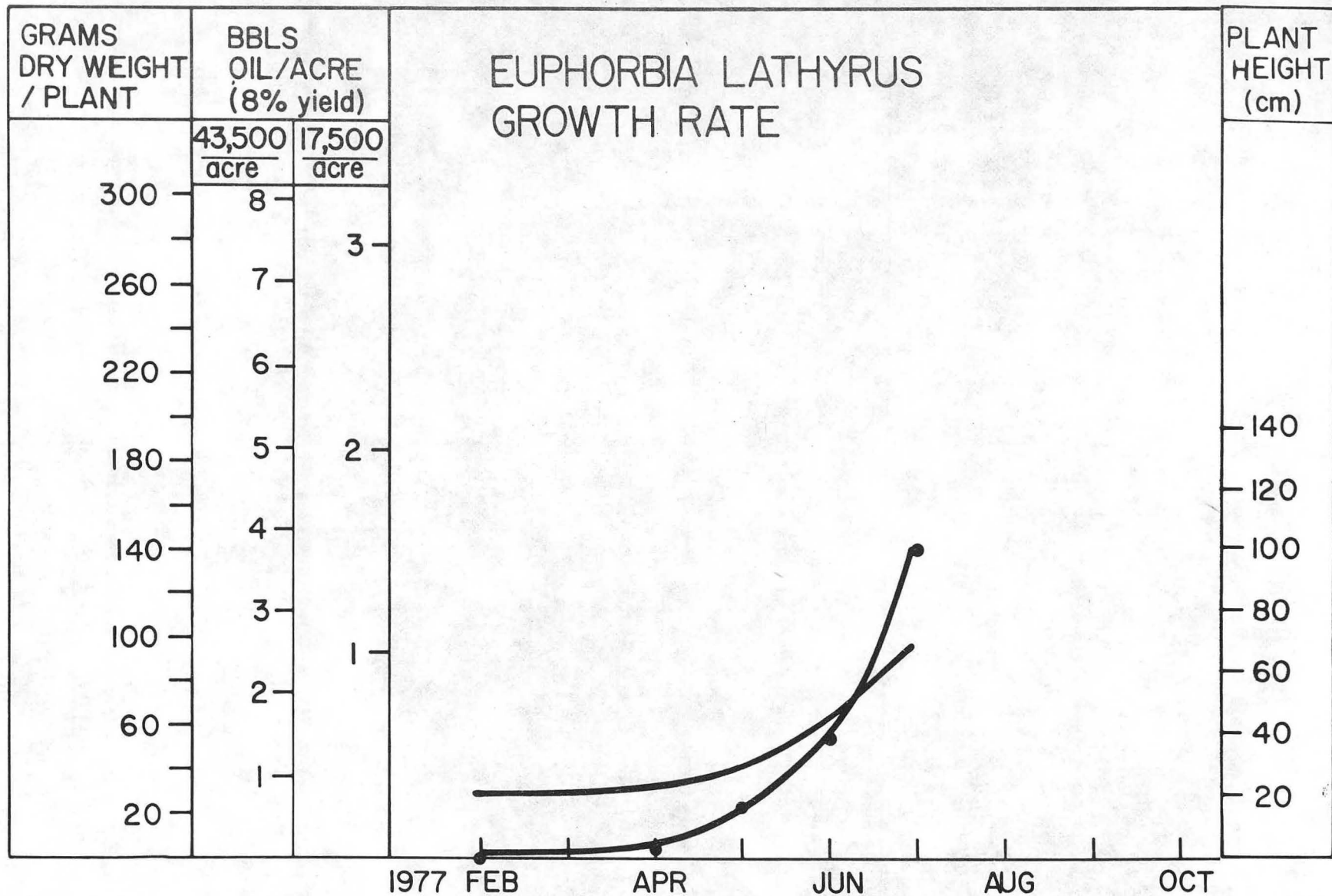
CBB 778-7451

Fig. 20B Euphorbia Trigona, South Coast Puerto Rico



CBB 777-6419

Fig. 21 Euphorbia Lathyris, South Coast Field Station, 6/77

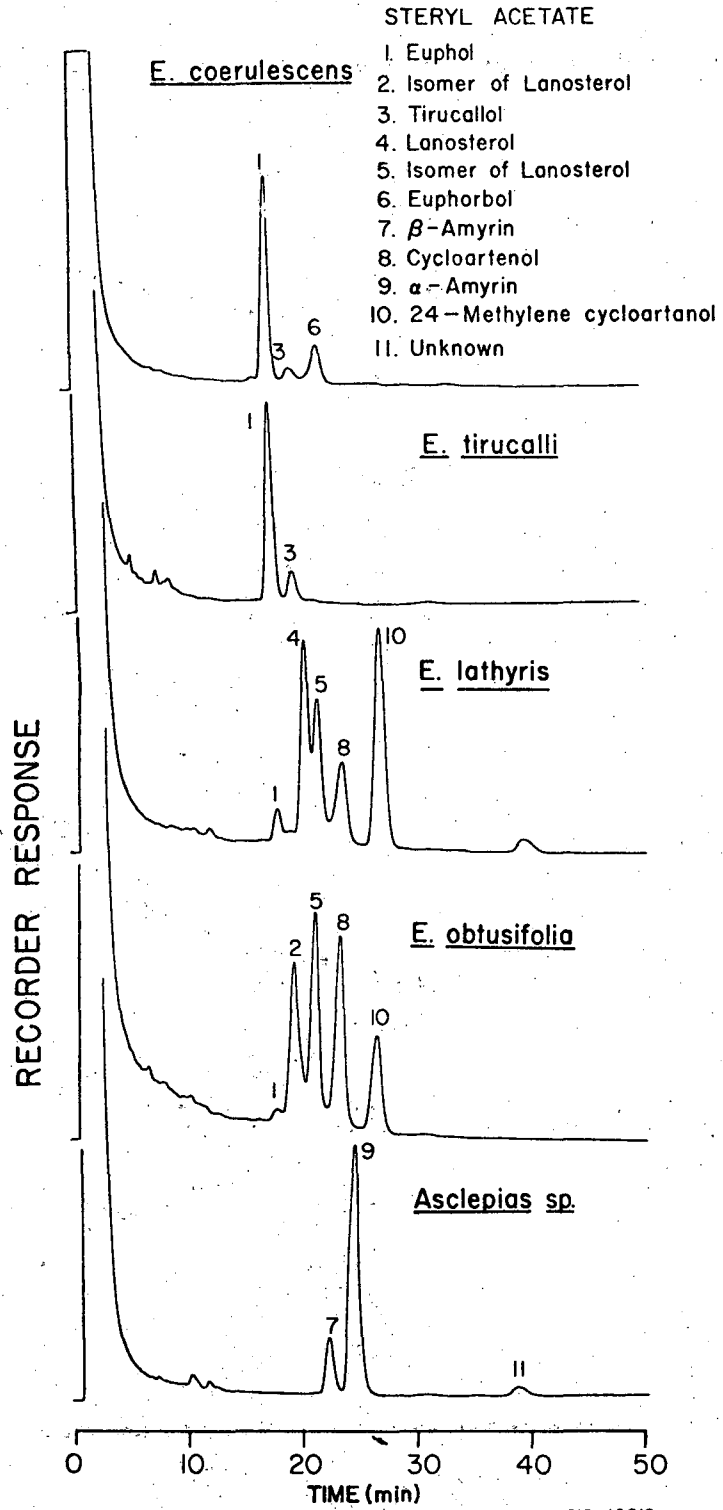


-40-

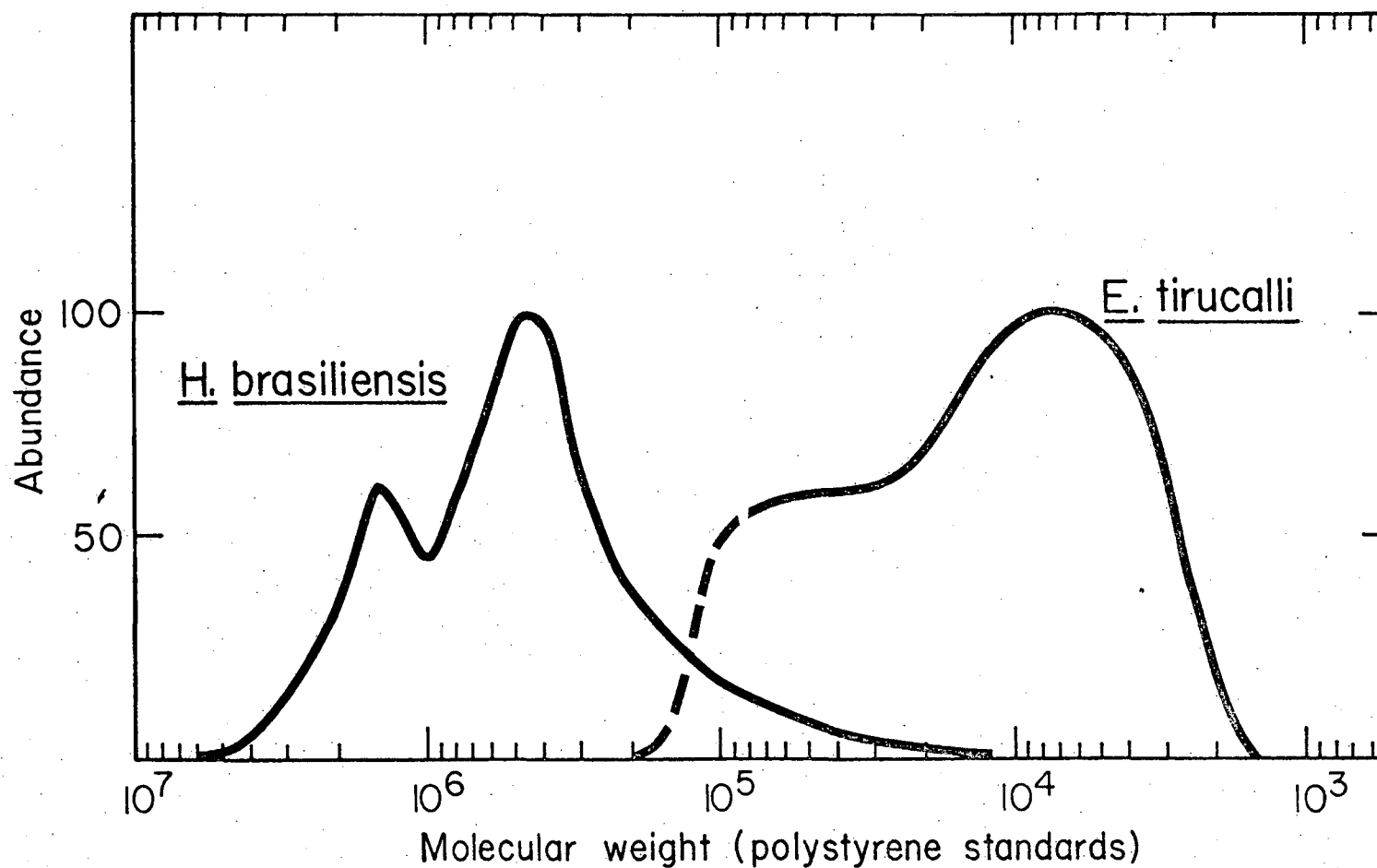
CBB 777-6959

Fig. 22 Growth Rate, Euphorbia Lathyris, 1977

GLC of Euphorbiaceae Steroids



Molecular weight distribution of polyisoprenes isolated from Hevea brasiliensis and Euphorbia tirucalli



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XBL 776-4455

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