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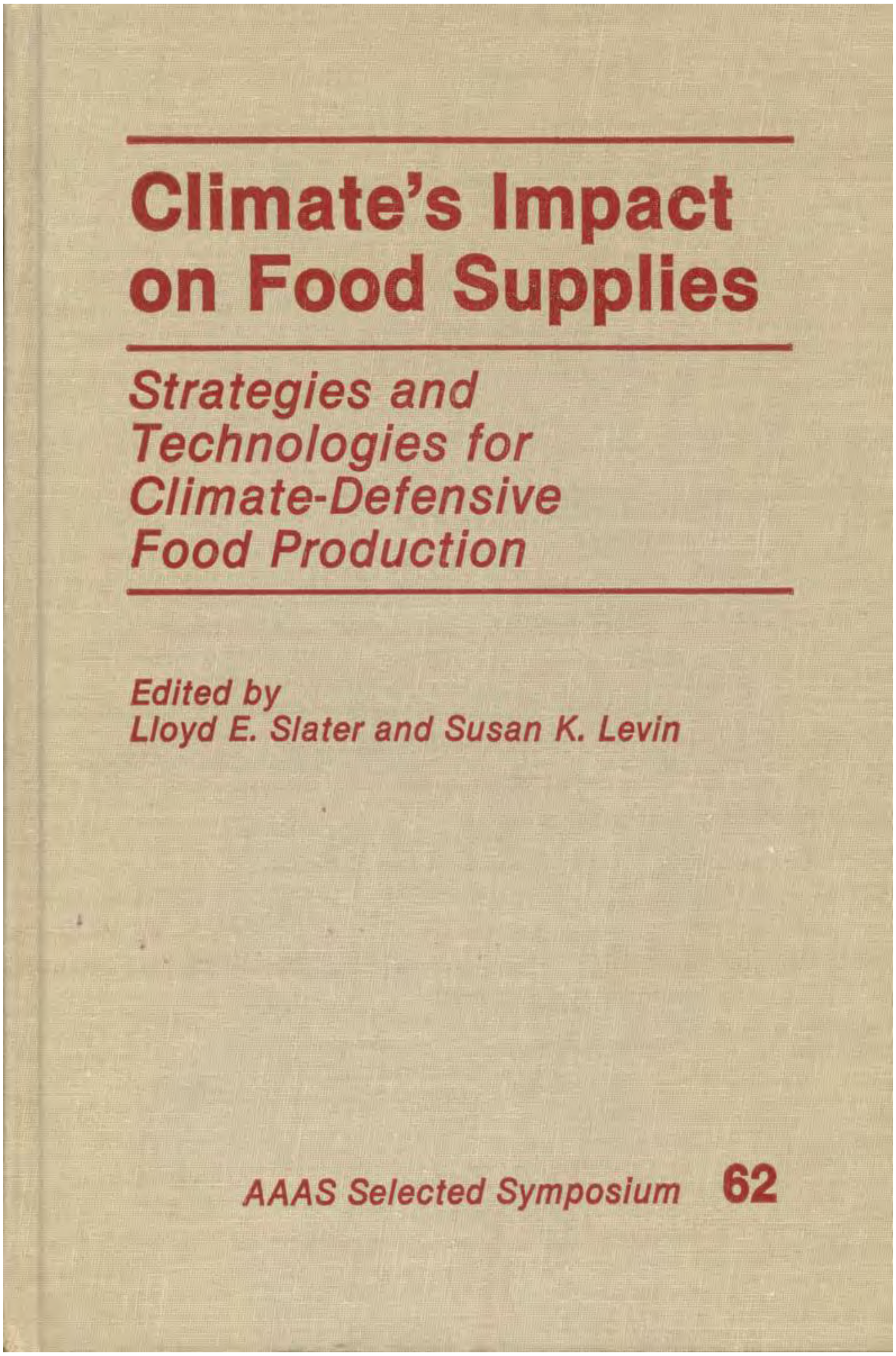

Climate's Impact on Food Supplies

Strategies and Technologies for Climate-Defensive Food Production

Edited by
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AAAS Selected Symposium 62

AAAS Selected Symposium 62
Published in 1981 – based on symposium held in 1980

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Introduction

Walter Orr Roberts

From the earliest times, scholars have speculated about the waxing and waning of civilizations. In his *Timaeus*, written around 400 B.C., Plato recounts the advice given to Solon, the wisest of the Seven Sages, by an aged Egyptian priest. "Solon, Solon, you Greeks are eternal children," the priest warned. "There have been many occasions of human destruction, and there will be many more. The chiefest source of these is fire and water…" By the words fire and water, the priest meant the scourges of drought and flood that had ravaged Greece. Plato's priest went on to say that the Egyptians, unlike the Greeks, preserved ancient lore and history. "Whenever anything great or glorious or otherwise noteworthy occurs, it is written down and preserved in our temples; whereas among you and other nations,…recently has recurred like a plague brought down upon you a celestial current (meaning the droughts and floods), leaving only an unlettered and uncivilized remnant; wherefore you have to begin all over again like children, without knowledge of what has taken place in older times whether in our land or yours…."

Rhys Carpenter, writing in 1965, used these and other recollections from Plato to preface his fascinating book, *Discontinuity in Greek Civilization*. It is difficult for us today to think of ancient Greece as a developing country compared to other nations of its time, but it is engrossing to realize there is so old a perception of climate as a major cause of human disaster.

In the same book, Carpenter speculates that the fall of the Greek city Mycenae, around 1200 B.C., was due to successive years of severe drought, even though Athens, less than 100km away, remained well-watered. In Mycenae, food riots and violent uprisings by the poor against authority led to the city's downfall. This may be one example of the kind of human destruction the aged priest was telling Solon about.

The Egyptian priest's caveat to Solon, though centuries old, nonetheless still holds: as long as the celestial currents bring down upon us devastating droughts and floods, man must take notice and dutifully record these occurrences, lest he "begin all over again like children."

20th Century Explanation

It awaited Reid Bryson of the University of Wisconsin to find a plausible meteorological explanation for how such a drought might have occurred in Mycenae, leaving nearby Athens unscathed. In recent technical papers in an excellent popular book, *Climates of Hunger*, Bryson suggests, with due caution, that a large-scale weather circulation pattern showing up in highly-reliable, modern records might provide the answer. The weather pattern would simply have had to become relatively more frequent and persistent to produce the juxtaposition of drought in Mycenae, yet ample rainfall in Athens.

Other popular books by authors such as Ellsworth Huntingon, Nels Winkless III and Iben Browning also call attention to recurring significant impacts of climate fluctuations and trends on human affairs. One of the best recent books on the subject is *The Genesis Strategy* by Stephen H. Schneider. Schneider graphically discusses the dependence of human wellbeing on stable climate, and calls for a worldwide political strategy, a "genesis strategy," to establish international grain reserves large enough to accommodate human crises triggered by climate, wherever and whenever they occur – as most Book of Genesis in which Joseph interprets the Egyptian Pharaoh's dream, is to store grain in the "seven good years" for the "seven lean years."

Though millennia have passed since the fall of Mycenae, it was not really until the year 1972 that public attention everywhere focused on the critical equation of food, climate, and human welfare. In that year, several climate anomalies in different geographical locations had serious consequences: 1) an extraordinarily hot summer and very little rain in the Moscow area caused the Soviets to resort to massive grain purchases on the international market to maintain livestock herds; 2) the Indian monsoon commenced late, was interrupted in mid-season, and ended early, thereby heavily damaging grain crops; 3) the six-year drought in the Sahel region of Africa climaxed with near total eradication of cattle herds of the nomadic peoples of the region; and 4) the anchoveta crop of Peru suffered a calamitous failure, wreaking havoc with fisheries and materially reducing the protein supplies of Latin America. Total world production of food down-turned for the first time in many years, and though the aggregate decline was but two percent, the impact in some localities approached disaster.

The pitiful state of refugee nomads of the Sahel saturated the press everywhere, and the impact of the African drought, which extended all the way to Ethiopia, became a driving factor in planning the United Nations Conference on Desertification. It built momentum for the World Food Congress in Rome in 1974, and gave great thrust to a drive to establish world grain reserves for just such disasters. In the United States, it spurred the entirely voluntary Hunger Project, with its aim to end world hunger within a decade. Heightened consciousness of the growing specter of malnutrition among the world's poor spawned the Presidential Commission on World Hunger.

Research Sharpens the View

In May of 1974, the International Federation of Institutes for Advanced Study (IFIAS) assembled an international planning workshop at the University of Bonn to identify top-priority studies on climate's impact on society, which merited research of a cross-disciplinary nature. From among over 20 suggested topics, attention focused on the task of examining the social, political, economic and ethical impacts of climate changes on the character and quality of human life.

Within a few months, and before a detailed plan of the IFIAS study had materialized, the magnitude of the 1972 anomalies and the severity of their human implications reached the attention of all. In the spring of 1975, the IFIAS project firmed up around the notion of examining specifically the topic of "Drought and Man: The 1972 Case." And in the fall of 1974, IFIAS issued a widely circulated appeal for new attention to the problem.

Excerpts on changing climate from the 1974 meeting statement still have a strong ring today:

"We must anticipate that such deviations or 'anomalies' will recur. At this moment the world is unprepared to cope with them. Grain reserves which used to be abundant in some regions are no longer sufficient to serve as insurance against disaster and by some estimates have dropped to such low levels that they can supply the world needs for less than one month at present consumption rates. At the same time wasteful and excessive consumption by the affluent, along with increasing numbers of mouths to feed, strains the capacity of farmers to deliver enough food even from the best of harvests. It becomes ever more difficult, expensive and risky to open up new arable land, and at least as difficult to limit the use of marginal lands highly vulnerable to erosion and worsening of climate.

"In short, the current food-production system now has little flexibility with which to meet emergencies. What we have hitherto regarded as occasional emergencies, moreover, can no longer rationally be so regarded.

"The nature of climate change is such that even the most optimistic experts assign a substantial probability of major crop failures within a decade. If national and international policies do not take such failures into account, they may result in mass deaths by starvation and perhaps in anarchy and violence that could exact a still more terrible toll. It would be irresponsible in these circumstances to continue passively in our present condition of helplessness: without food reserves or alternative technologies to produce food, and without adequate means to redistribute food from the more favored nations or more favored groups within nations to the less favored in time of urgent need."

The distinguished Argentine scholar Rolando V. Garcia was selected to head the IFIAS three-year study effort. From this investigation has come a new perspective on food-climate interactions. The widespread publicity of the misery of the tragically malnourished children of regions of Africa and in Bangladesh resulted in a perhaps overly-simplified perception by most people of climate's impact on food supplies. The report of the IFIAS study under Garcia draws a full picture of the multifarious components surrounding and incorporating the food-climate connection. I strongly recommend Garcia's volume. It has in it some harsh judgments about where blame lies, and some will contest a number of its imputations. But it is an important step towards the development of a more balanced perspective about the root causes of world hunger. Only if new and more balanced perspectives become widespread will we have much hope, I suspect, of conquering malnutrition among the world's poor.

While another article in this volume gives some of the principal findings of Garcia's IFIAS study, it is enough for me to say here that the human tragedy resulting from a drought or a flood is not simply the food lost. It is a far more complex socio-political matter, somewhat exemplified by this passage from the *Politics of Starvation* by Jack Shepherd and published by the Carnegie Endowment for International Peace:

"Between March and September, 1973 – the worst periods of the famine in Wollo and Tigre provinces – there were some 20,000-30,000 tons of grain stored in commercial warehouses around Ethiopia….An American embassy officer in Ethiopia reported seeing 'peasants starving to death within a few miles of grain storage'….As long as large amounts of relief grain were held off the market, or preferably, not even brought into the country, shortages (and high prices) could occur and profits could be made….As prices rose, at one point the Ethiopian government offered to sell 4,000 metric tons of grain it had in storage to the United States, which could then donate it back for relief inside Ethiopia."

The Problem Intensifies

Today nearly one-fourth of humanity lives on the razor edge of damaging malnutrition. These are the world's poorest, and perhaps a half of them will lead short and tragic lives as a consequence of their plight. The problem is not going away as world affluence grows; instead, it seems destined to intensify year by year. By the end of the next five or six decades I expect we will see our world characterized by:

- doubled world population,
- tripled world food demands,
- quadrupled world energy consumption.

With these changes will come mounting costs for pollution control; worsening shortages of good quality water for irrigating the 17 percent of the world's cultivated land that now yields 50 percent of all agricultural products; accelerating degradation of the environment as more marginal lands are farmed and as world forests are decimated; increasingly expensive food in world markets – and the list could go on much further. Moreover, it is entirely possible that meeting these demands will produce unplanned human impacts on the stability and character of the earth's climate.

Most climate experts are convinced, for example, that carbon dioxide in the atmosphere will double over this time span, mainly as a result of the burning of fossil fuels for energy use. With this CO_2 doubling we will suffer an average climate warming of two to three degrees C in mid-latitudes. This is a change of magnitude probably unprecedented since *Home sapens* first walked the earth.

If the anticipated CO_2-induced warming happens, there will be considerable effects on the world's agriculture. Some regions of the earth are expected to have more rainfall, some less. On balance, such a climate change could do more harm to world food supplies than good. With more mouths to feed, we will probably have a difficult time producing the needed food from most of the earth's present 1.5 billion hectares of cultivated land.

We clearly face a time of challenge and of tough choices. I am confident that innovative approaches will make it possible to meet human needs, but I am also certain that in so doing we will have to develop new perspectives not only on food and climate, but also on mankind's way of doing things politically, socially, economically and morally. It is not a time for business as usual, if we hope to see business survive at all.

3. Uses of Climatic Knowledge in the Food Systems of Developing Countries

Roger R. Revelle

Introduction

In developing nations, climate has its greatest impact in the zones of widest climatic variability – the warm, semiarid and subhumid zones, particularly the regions where monsoon rains prevail. These include nearly all of the Indian subcontinent; the semiarid and subhumid regions of China; Thailand and parts of Indo-China; much of the Middle East; part of Africa north of the Sahara; the Sahelian zone south of the Sahara, extending from Senegal through the Sudan to Ethiopia; parts of southern Africa; northeast and southwest Brazil and parts of the central Brazilian plateau; northern Mexico; large areas of Argentina and Chile, and the coastal zone of Peru. Present populations in these regions total more than 1500 million people – more than 50 percent of the developing world.

With the rapid growth of populations in developing nations, a sustained high level of agricultural production is becoming more and more critical. All resources are being stretched closer to their limits, and climatic variability is an increasing threat to the survival of people at the margin of subsistence. Fortunately, the climates in most of these regions are warm, so that crops can be grown throughout the year, provided sufficient water can be made available.

Three kinds of knowledge about climate are important in the less-developed countries; 1) the statistics of climatic variability, determined by suitable measurements over time and space, combined with the analytical manipulation of these measurements; 2) the ability to make short-range probabilistic forecasts of what the weather is likely to be a month to a year from now, and 3) the probability of climatic change – i.e. the probability at some time in the future of a change in the mean state of the climate and/or in the frequency distribution of different states. From the standpoint of decision-makers, the first kind is the most important.

How Farmers Assess Climate Impact

Decision-making in agriculture occurs primarily at four levels: the individual farmer, the agricultural sector in a particular country, the national level, and the global society as a whole.

In traditional peasant agriculture, the farmer’s decisions as to what crops to plant and when to plant them were made long ago, over many generations, by a combination of trial and error and canny observation of local climatic variability. The principal basis of these decisions was risk-aversion – the necessity to produce enough food for survival in years when the climate was “bad.” Market forces had little influence because the crops were not sold, but consumed within the village. And few decisions were necessary at the sectoral, national, or international levels.

With the unprecedented growth of populations in developing countries during this century, a transformation to market agriculture has become necessary. This means that the farmer must buy fertilizers, farm tools and machinery and other inputs in order to increase his yields per acre, and he must sell a large part of his crop to pay for these inputs. With market agriculture there is much more flexibility, and the farmer must make decisions each years as to what crops to plant, when to plant them, the quantity and kind of inputs to purchase, and when to sell his harvest. Moreover, decisions need to e made at sectoral, national, and international levels, to ensure as adequate a food supply as possible for large and growing populations.

The farmer's decisions will be better if he can take account of the probability distribution of the timing and quantity of water supplies, potential evapotranspiration, and solar insolation. In a region of low and uncertain water supplies, he will plant millets instead of maize in the African Sahel and groundnuts instead of rice in Indian Saurashtra. He will be reluctant to borrow money to buy fertilizers. Where the danger of floods during the monsoon season is high, the Bangladesh farmer will plant floating rice, or nothing at all, and concentrate his efforts in the sunnier, more dependable winter seasons. If even moderate rainfall is likely in April and May, the Pakistani farmer will not plant cotton, because the cotton will waste its photosynthetic production in vegetative growth, and what bolls do develop will be severely damaged by pests stimulate by the moist environment. In regions where the monsoon starts and stops intermittently, the farmer will hold back half or more of his seed, to be able to make a second or third planting if the first planting fails for lack of moisture.

Agroclimatic information collected and interpreted by competent interdisciplinary scientists will be especially useful at the farm level in areas of rainfed agriculture, where crops that are not traditional for a particular region, such as fruits, nuts, vegetables, soya beans, and oil seeds, are being introduced for the first time. AT the sectoral level, the agro climatologist can give climatic specifications to the plant breeder who is attempting to produce better-adapted varieties.

Climate-Responsible Water Management

In most of Asia, rainfall and runoff are concentrated in the few months of the monsoon season. Irrigation and drainage development and flood protection, at a total estimated cost of ore than $100 billion, are essential if agricultural production is to be increased sufficiently to feed the growing population during the next 25 years. Besides providing water to farmers in the dry season, thus permitting two or three crops to be grown during the year, surface reservoirs and wells will smooth out the variability in water supplies within the rainy season. If the underground aquifer is sufficiently large, it will also be possible to reduce year-to-year variability by pumping down the water table during the dry years and recharging the groundwater during wet years.

Accurate information on the frequency distribution in time and space of rainfall and runoff throughout a river basin is obviously essential for the design of irrigation, drainage and flood-control systems. But it is less obvious that such information is also necessary to optimize the management of these systems after they are constructed. In operating a surface reservoir, for example, the principal action involving a human decision is to release water through the penstocks and electricity-generating turbines or the irrigation tunnels in the am. Though the action is simple, the decisions as to when and how much water to release throughout the year are complex. They will depend on often conflicting demands for irrigation and for electric power, on the economic and political weights assigned to these two uses, and on the best available estimates of river runoff into the reservoir during the remaining months of the year. All three of these decision factors rest in part on climatic statistics.

In the management of an underground reservoir, the mean depth to the water table should be maintained at an optimum level, such that water-logging and high evaporation rates will not occur during one or several years of heavy rainfall or river runoff, while pumping costs will be kept as low as possible after one or several dry years of heavy rainfall or river runoff, while pumping costs will be kept as low as possible after one or several dry years. Again, information one year-to-year climatic variability is essential.

At the national and international levels, the size and location of food-storage facilities the quantity and kind of food reserves, the tonnage of ships for international food transfer, national pricing and procurement policies for agricultural products, and planning and institutional development for imports and exports should all be (but seldom are) based in part on both regional and global statistics of climatic variability.

Would Climate Forecasts Help?

Would climatic forecasts over one to 12 months help decision-makers at different levels? Under present conditions, such forecasts might be least useful to farmers and most useful at national levels. What does the farmer do wit ha forecast that says there is 75 percent probability that next season’s rainfall will exceed 400mm, instead of the 50 percent probability given by the statistics? Doubtless he should do something, e.g. plant a more water-sensitive but potentially more profitable crop or increase the amount of fertilizer that he will apply. But he is not likely to do either of these things unless sectoral or national actions are taken to assure the prices he will receive if he has an abundant harvest and to insure him against crop failure if the forecast turns out to be wrong.

At the sectoral level, climatic forecasts would enable fine-tuning of the decision rules for release of reservoir waters. Forecasts of higher than normal rainfall or runoff should also stimulate planning and mobilization of measure for flood control. Forecasts of future weather conditions leading to increased pest populations would be helpful in organizing plant-protection measures.

At the national level, both regional and global Agroclimatic forecasts would be useful in setting procurement prices, planning and allocating resources for food imports, or planning and organizing for exports of agricultural products. At the international level, no institutional mechanisms for using global forecasts and little realization of the need for them now exist. But this does not mean that such institutions are not needed.

There is, however, a distressing shortage of data concerning hydrologic and other climatic parameters in most developing countries. Often only a few limited types of observations of questionable accuracy are available for only a few years. One of the important problems of climatology is to find and apply methods of data analysis that will make it possible to use short series of fragmentary, inaccurate measurements in helping to improve the food systems of developing countries.

Harnessing Climate for Energy

Planners and decision-makers in the less developed nations should consider use of climatic information for the development of energy sources for agriculture. Maps of the monthly distribution of wind velocities, for example, would define areas where wind energy can be effectively and economically deployed – e.g. for pumping irrigation water. The number of days per month in which the average wind velocity is less than two or three meters per second (below which windmills characteristically do not work) would determine whether win d power might be a practical energy source. The balance between thermal and hydroelectric power plants in any region depends on the frequency and length of droughts that reduce the water supply to reservoirs and increase the demands for power for pumping irrigation water. The 1972 drop in agricultural production in India was in part due to the fact that the nearly empty reservoirs could not supply sufficient electric power for pumping, and there was too little backup from thermal power stations.

Development of biomass energy for use in producing and processing food, either from agricultural residues or from fast-growing trees, must take account of both average climate and its variability. Fore example, the anaerobic bacteria that convert animal and plant wastes into methane in biogas converters operate efficiently only over a narrow temperature range. Biogas converters will not be very useful when the annual temperature range is too great. Selection of fast-growing tree species for energy plantations depends on the balance between water supply and evapotranspiration at different seasons of the year, on humidity annual temperature regime and soil-water relationships, and on the variability of all these factors from year to year.

Climate and Fish Production

Several fisheries in less-developed countries – notably the anchovy fishery off Peru, the shelf fishery off India’s Malabar coast, and Korea’s wide-ranging distant-water fishery – appear to be more or less critically dependent on variation in oceanographic conditions, i.e. in the oceans climate. For example, Peru’s anchovy catch went from 12 million to less than 2 million tons in one year following the occurrence of the oceanographic phenomenon called “El Nino,” an occasional invasion of warm water into the usually cool waters of the eastern equatorial Pacific. While most fish production in less-developed countries comes form shallow-water nearshore or fresh water fisheries, the latter often in man-made ponds, the fact that fish provide about 10 percent of the protein available to the present world population (and a much higher percentage in many poor countries) underscores the necessity for further study of climate's effect on fish productivity.

Finally, Man's Impact on Climate Itself

At present, our level of understanding of possible long-term changes in the main state or the year-to year variability of the global climate is low. For example, we are unable to estimate changes in patterns of precipitation and runoff with an increase in average air temperatures which might be brought about by an increase in atmospheric carbon dioxide. Under these circumstances, planners and decision-makers in less-developed countries cannot be expected to take much account of these possible changes. The world community, however, should act to ensure that sufficient planning and investments in irrigation, drainage, and energy conversation are undertaken to prevent a deterioration of per capita food supplies that might result from adverse long-term climatic changes brought about by the profligate use of energy in developed countries.

The leaders of less-developed countries can be expected to take greater responsibility for those actions by their own citizens that may be causing deterioration in the regional hydrologic cycle. For example, destruction of forests in the Himalayan foothills of Nepal, India and Pakistan is probably resulting in more frequent and more severe floods in the Indo-Ganghetic Plains, on which more than 400 million people depend for their food supply. Equally serious, although less certain, maybe a steepening of the river hydrographs, i.e. and increasing concentration of annual river flows during the four months of the monsoon season, because of destruction of water-holding vegetation and soils. This may diminish surface water supplies for the winter crops.

11. New Options for Climate-Defensive Food Production

Carl N. Hodges

The tremendous impact of climate on food production can be moderated – and in some cases virtually eliminated – by applications of environmental control. Such beneficial manipulations range from the simple to the complex; the extent to which the technology is applied is usually determined less by the limits of knowledge than by the availability of resources and by cost-effectiveness.

Sunlight, for example, is the ultimate energy source for all food production. Plants use it to convert water and carbon dioxide into carbohydrates. Yet the major agricultural areas of the world are not the sunniest areas of the world. This is because historically a balance had to be struck between available sunlight and available rainfall, which is still agriculture's primary source of water. So the earliest and most significant type of environmental control is irrigation; by supplying water artificially to plants, it became possible to develop agriculture in areas of maximum sunlight. Such regions have become the most productive on the globe; sufficient water is available for plant growth, but clouds do not shade the land as the water is delivered.

This primary type of climate control has severe limiting constraints, however. We have already developed most of the world's potential for irrigation; we have done most of what we can where sunlight, fresh water and arable land are all available and can be joined realistically. And, in the sunny, arid regions which become so productive with the application of water – i.e. the deserts – we tend to load the fields with residual salts.

A desert, by simplest definition, is a place that gets less water than it loses by evaporation. About 35 percent of all the land on earth – 18 million square miles – is classified as desert, including a third of the North American continent. This does not mean that all deserts are hot and glaring with sunlight – there is a big one in Asia that is frozen solid a good part of the year – or utterly without water and uninhabitable. It does mean that they get little rain and have high rates of evaporation. The latter distinction is important because it causes us to manufacture more desert every year. We do this with the best of intentions – we are trying to grow food on more irrigated land – but the simple desert phenomenon of evaporation is getting ahead of us. About a half million acres of crop land are estimated lost each year in this manner.

The problem is not so much that a great deal of irrigation water must be used, although this in itself is critical in the desert, where there is only so much water available. Sometimes the water table drops so far one can't afford to pump it up anymore. But the problem we address here is that when the water evaporates it leaves its salts behind in the soil. Year by year the land gets saltier and the crop yield gets poorer until finally practically nothing will grow. Conditions deteriorate quicker if the water is brackish, and desert water often is. The land is abandoned eventually, more unusable than ever before.

The continuous loss of arid land to salinization is nothing new. Whole ancient civilizations are believed to have wiped themselves out this way, helping create the formidable deserts of the Middle East and North Africa in the process. But the phenomenon is also dangerously contemporary. The state of California grows a large part of most American foodstuffs, yet the build-up of salt in the soil is now said to affect half of its crop lands to one extent or another. The problem is common to much of the southwest United States and northwest Mexico. The two countries share the same geographical deserts – the Mojave, the Sonoran and the Chihuahuan – and like those in the United States, the Mexicans haven't been at all sure what to do about salinity.

Is Fresh Water the Limiting Factor

It is disappointing that on this lush planet, with a full two-thirds of its surface covered by water, there is so little usable fresh water available. Almost all of it is locked up in the oceans, the ice caps and the glaciers. Less than one-half of one percent of the world's water is theoretically available for crop irrigation and all other human needs. Much of it, in fact, society itself has rendered at least temporarily unusable, especially in the developed world. Yet there is an immensity of salty water confronting us, not only in the oceans, but also in the saline ground water which underlies much of the land. Two-thirds of the land mass of the United States lies above saline water of more than 1,000 parts per million (ppm). But even more compelling is the presence of 20,000 linear miles of desert seacoast in the world, backed by unknown millions of acres of empty land, drenched in the highest levels of solar radiation. Consider the coasts of North Africa, the Arabian Peninsula, much of the Indian subcontinent, the Atacama of South America, the western coast of Australia, and the more than 2,000 miles of desert seacoast on both sides of Mexico's Gulf of California.

At the same time, consider also that those of us who have grown up in the desert have always been fascinated by the challenge of "making the desert bloom." This dream is exaggerated when one stands on a desert seacoast and looks out at all of that blue water offshore. If only we could remove the salt from the seawater and use it to irrigate the land. The University of Arizona's Environmental Research Laboratory (which the author directs) made an effort in this direction in the 1960s. We developed a solar-powered desalting plant that performed as designed and was probably about 20 years ahead of its time. Despite its technical success, however, this solar plant suffered from the same malady that still afflicts a great many solar applications today: it was just too expensive to consider using such product water, even under the most optimistic projections, for conventional open-field agriculture.

The increasingly prohibitive cost factors in desalinized seawater irrigation leave us with two choices: 1) We can try to reduce the water requirements of conventional food crops – which was our laboratory's first approach to the problem, or 2) We can try to do something with seawater itself, something other investigators have tried for years, but which we are now attempting from several points of view.

First: CEA to Conserve Water

Our laboratory's first approach, from the late 1960s through the early 70s, led to sophisticated applications of Controlled-Environment Agriculture (CEA) in the deserts of the United States and the Middle East. Rather elaborate greenhouses are used to encapsulate an artificial environment. In there, air is circulated through a spray of seawater to cool and humidify it, producing a rainforest environment, but with high levels of sunlight. Vegetable production is prodigious, and little fresh water is necessary, as the humid atmosphere reduces plant evapotranspiration to a fraction of what it would be in the open desert. The net effect is climate control, as well as water conservation. So little fresh water is needed relative to the high levels of food production, that all other things being equal, even very expensive water from a desalting plant can be economically feasible. There are several large-scale applications of this technology producing special high-value crops in both hemispheres. Fig. 1 and Fig. 2 show CEA installations, designed by the Environmental Research Laboratory (ERL), at Abu Dhabi and near Tucson, Arizona.

Fig. 1. A two-hectare controlled-environment agriculture facility located on Sadiyat Island, Abu Dhabi, designed by the Environmental Research Laboratory.

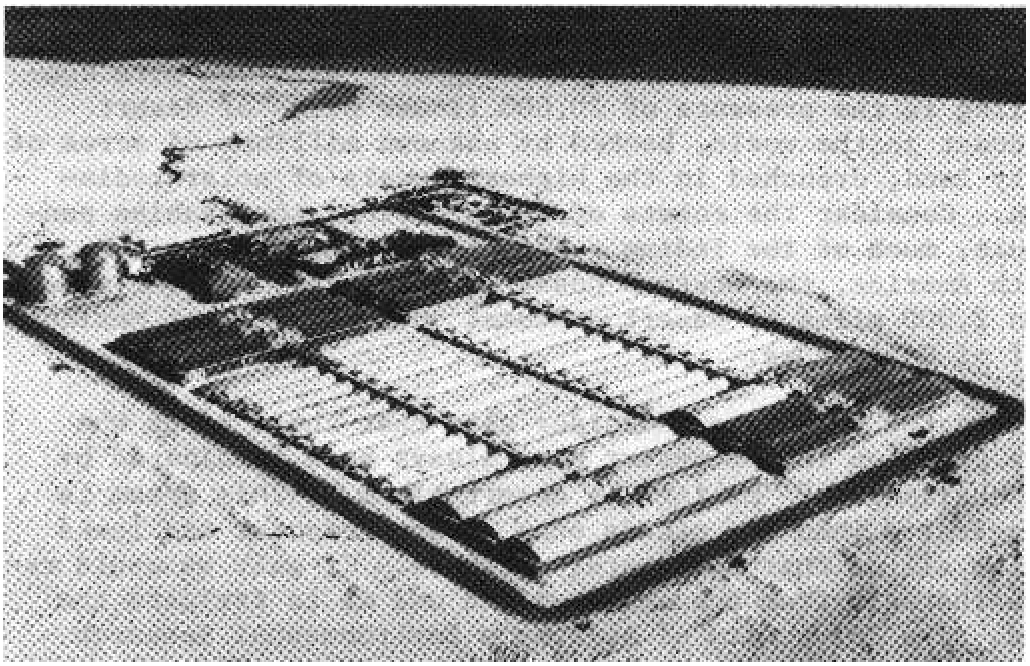


Fig. 2. Superior Farming Company, Tucson. A ten-acre controlled-environment agriculture commercial facility designed by the Environmental Research Laboratory.

The major constraint in CEA, however, is again a matter of economics. A total CEA system is capital-, energy- and labor-intensive; it may not use much fresh water, but it uses a great deal of money. In the United States, most commercial CEA greenhouses are marginal at best, and only those installations which produce for a very specialized market or for a captive market or for both make very much sense. (CEA systems are more common, and presumably, more profitable, and in parts of Europe and Japan.) We hope that innovative designs and new materials will reduce future structural and energy costs, and are still working to that end.

The other approach – using seawater directly for food production – is one of the oldest and most cherished hopes of mankind. There are a number of options to consider.

Seawater Farming

Perhaps the most obvious of all, the growing of food using seawater instead of fresh water is in ways extraordinarily difficult to utilize in modern production systems. Since conventional farm livestock cannot use highly salty water, we can fasten upon those economically desirable aquatic animals, particularly marine species, which can. And as it is increasingly inefficient to hunt fish on the open ocean (wasteful of energy and at the mercy of weather or unpredictable sea) we can bring the ocean onshore and there domesticate crops of sea animals – that is, engage in mariculture, or seawater aquaculture.

It may seem a little puzzling that the developed world, with all of its technology, has seen so few successful applications of aquaculture, an art that has long provided subsistence farming in parts of Asia and Africa. It hasn't been for lack of trying. Particularly in the decade from the mid-1960s to the mid-1970s, there was a national preoccupation with "oceanography" and "aquaculture" in the United States, and people were led to believe that large-scale farming and mining of the sea were going to happen immediately. What went wrong? It seemed to involve serenely simple technology. Everybody understood how a fish pond operates, and aquaculture essentially seemed a fish pond made bigger.

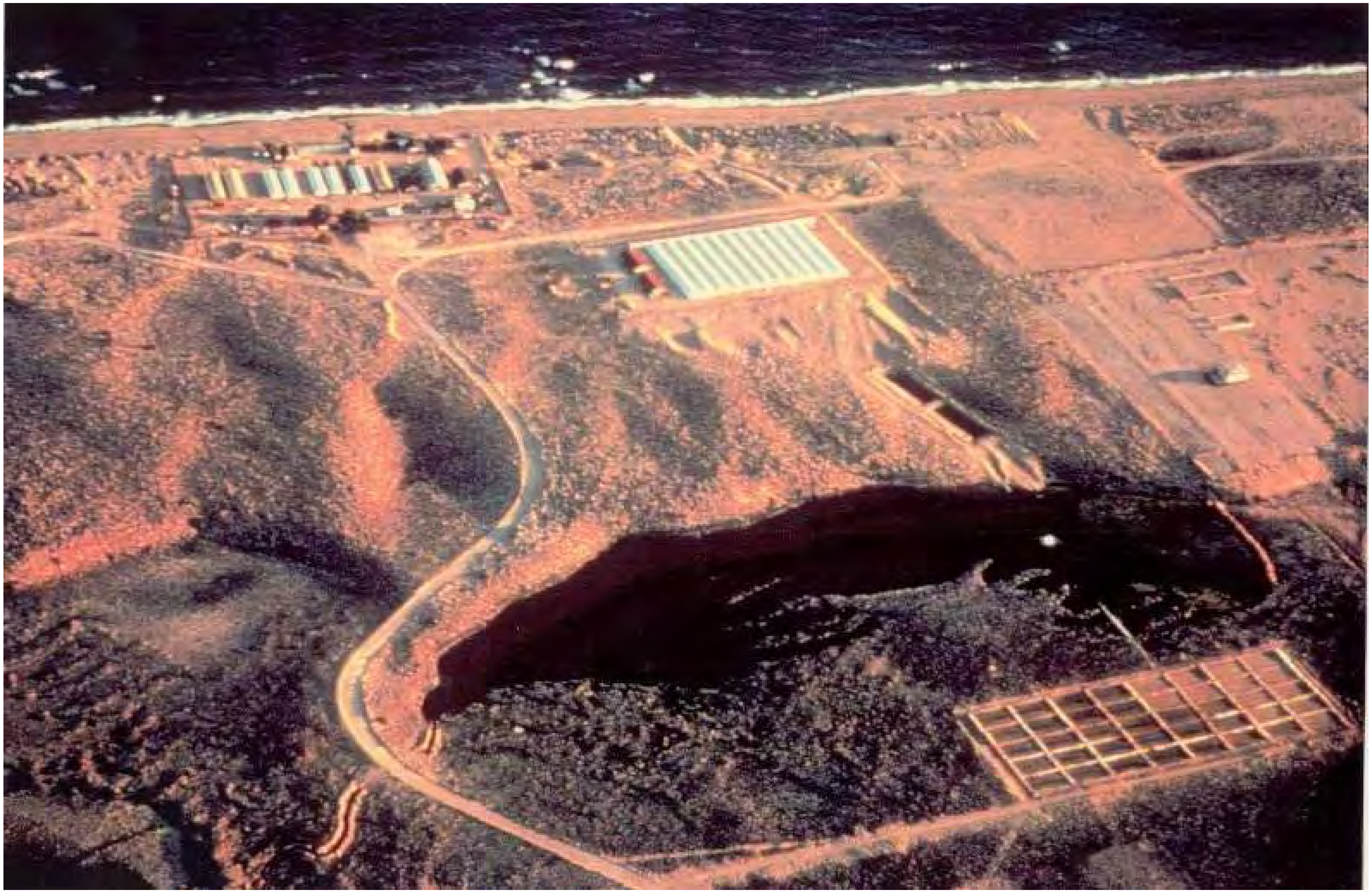
What went wrong was that we "pioneering" aquaculturists really didn't know what we were doing. We knew so little about the animals of the sea, and we still know very little. We simply did not understand that fish farming involves highly complex biological systems, and in an unfamiliar and corrosive medium. To some extent we recognized our ignorance, but our method of trying to learn was groping and ill-coordinated. Instead of a strong, centralized, mltidisciplined NASA-type assault on the problem, we settled for a scattered burst of unrelated, small-scale individualistic little research projects which produced hundreds of graduate degrees, tons of paperwork, and very few pounds of fish. At the same time, a handful of visionary and articulate entrepreneurs persuaded a succession of equally enthusiastic investors to initiate commercial aquaculture ventures. With few exceptions, these were mostly premature disasters. Altogether it was a rather sorry little history and created widespread disillusionment. It was comparable to some of the current disappointments in the field of solar energy; we believed because we wanted to, and we were led to expect too much too soon.

An Integrated Approach

It was in this context, in 1972, that the Environmental Research Laboratory began work in an approach combining climate control with the use of saline water in growing seafood. We did not expect the development of high technology aquaculture to be easy, and it wasn't. It took seven years and seven million dollars to develop a CEA system for the culture of marine shrimp. We deliberately selected such a high-value, luxury-food species as the initial cultured product, because there is a worldwide demand which far exceeds worldwide supply. We knew that the most efficient way for a university to disseminate a new food technology is to invent something that is clearly profitable; the dissemination then takes care of itself. We also chose to encapsulate the artificial aquatic environment, not for cooling and humidification as in the case of CEA for plant production, but rather to control light as well as to help elevate temperatures and protect a valuable crop of small animals from sea birds and other predators which so frequently devastate open-pond aquaculture.

In a large-scale project funded by the Coca-Cola Company and F.H. Prince & Company, and working with the University of Sonora, we took a species of commercial shrimp from the Gulf of California, brought it onshore at the Mexican research station shared by our two universities, and domesticated it. In our controlled-environment systems, the shrimp breed and reproduce themselves. Their offspring are grown by the millions to harvest size on a variety of artificial diets and at high-stocking densities undreamed of in conventional pond-based aquaculture. Instead of an objective of a ton of animals per acre per year, we can grow more than 50 tons per acre-year, and of a higher quality to bring a higher price. This is more shrimp from one acre than four local shrimp boats catch in a season, and with vastly reduced inputs of capital and energy. Our research sponsors are now beginning to commercialize this shrimp culture system in large-scale applications. Fig. 3 shows the installation at Puerto Peñasco, Mexico.

Fig. 3. Background: U. of Sonora Research Station in Puerto Peñasco, Sonora, Mexico, where cooperative research by the U. of Sonora and the U. of Arizona has continued for 17 years. Facilities for seawater aquaculture are in the middle.



Growing Salt-Tolerant Crops

The other options toward "biosalinity" production deal with plant agriculture. Certainly plant science research in this direction has not been inactive, but the work has been small in scale and spread out over a longer period of time. It also in some ways appears more complex, probably because so little is known about biosaline plant production. There are essentially three approaches toward using saline water to grow plants, the first and most obvious of which is to cultivate marine algae or seaweed. So far in the United States, culturing algae on shore has proven mostly unsuitable and unattractive for human consumption, economically impractical for livestock, and marginal at best for selected chemical extraction. Chances are this situation will improve, since there appears to be no particular economic or technical barrier involved. It is more a matter of discovering and/or developing better kinds of algae for this purpose.

The second approach is to find or develop strains of conventional land-based food crops which can tolerate higher levels of salt. This is a goal as old as agriculture and over the years a great many scientists have gone after it. What scientific literature exists on biosalinity – and there is not a great deal of it – mostly describes these scattered efforts. The work is still going on, with a few hints and promises, but with no real breakthroughs. Salt slows the growth rates of conventional crops, reduces their quality as well as their yield, and kills them at saline levels only a fraction that of seawater.

The third approach is newer. It is to explore those strange and neglected plants which have evolved naturally in highly saline soil – halophytes, named from the Greek words for salt and plants – seeking any which can be domesticated and cultured as human food, animal fodder or chemical feedstock.

Returning now to our shrimp culture effort, just to do its front end research required pumping large volumes of seawater through our buildings at up to a thousand gallons a minute. (The commercial farms will have to pump much more.) From the shrimp raceways the water is ejected into wastewater lakes where cultured marine algae are grown, removing the excess nutrients before it percolates back into the sea. We can and do cycle some of the marine algae back into the formulated shrimp feeds we have developed.

It occurred to us that having all this pumped seawater on hand was a marvelous opportunity for our plant scientists to initiate some new work in seawater agriculture. Some University of Arizona scientists had tried saltwater irrigation ten years earlier, but only with conventional food crops and only with the usual unsatisfactory results. So we were still not too optimistic about the undertaking.

Seawater Irrigation

In this new endeavor we wished to try something different. If conventional crops cannot be grown in seawater, a more pragmatic approach would be to see what kind of plants can be grown with saltwater irrigation and then determine their utility. We could easily observe that the weedy plants found naturally on desert seacoasts can handle high salinities, high temperatures and high levels of solar radiation. The question was whether any of them would be good for human uses.

We did have some clues. We found it was already known that in earlier times the Seri and Cocopa Indians who roamed the bleak coasts of the Sonoran Desert used almost any seed-plant they could get their hands on – about 80 different species, surprisingly, including some estuarine plants – for one purpose or another. They couldn't afford to let anything that grew go to waste in that hostile environment. At the same time, and independent of our reflection on this, we were approached by an ethnobotanist from the Arizona-Sonora Desert Museum. He said that he had been told by back country missionaries in Mexico that the Seris' unwritten history has it that they used to harvest a seed crop from a specific coastal halophyte and grind it to make bread. He thought, with out abundance of pumped seawater, we might want to take a look at such a plant. Then, in yet another independent development, we were approached by a scientist from the University of Delaware, one of the few anywhere who had started culturing halophytes. After visiting our shrimp research station, he enthusiastically urged us to start investigating these strange plants, and offered to join in the effort. This considerable amount of coincidence helped us set our research plans.

Halophytes are unusual plants and there is little known about the details of how they function. They can handle much more salt than any of their related species, and the desert halophytes have to tolerate a burning sun and high air temperatures as well. It is these desert species which have obviously evolved some unusual photosynthetic pathways to avoid destruction from salt and sun. How do they do this?

How Plants Handle Salt

Plants in general can do one of two things when supplied with salty water. Most simply refuse to let salts into their systems at all, which solves the problem rather well. However, this also means such plants are depriving themselves of water, which does little for their survival if there is nothing but salty water available. The second choice is for a plant to take up the water, salts and all, using the water and rejecting the salts, either by extruding them or by isolating them within the plant tissue somewhere they cannot cause harm.

The halophytes we are working with seem to employ the tissue-isolation mechanism. How they manage this is something we would not have been able to understand many years ago, before it was learned that there is more than one way for a plant to photosynthetically produce carbohydrates.

Most common domesticated food and forage plants utilize the C3 photosynthetic pathway; i.e., they require considerable carbon dioxide, so they must have wide-open leaf pores, even during the hottest period of the day. This in turn permits water to evaporate from the leaves. If there is plenty of water for the roots to take up and deliver to the leaves, this is not too detrimental, since the plants thus achieve evaporative cooling at the same time. To conserve water, however, most halophytes use C4 or CAM pathways which permit them to keep their leaf pores partially or completely closed during the day and open only at night. They thus obtain their required carbon dioxide, but they can reduce their water requirement by more than one-half. For example, a typical C3 plant may need 500 grams of water to produce a gram of dry matter, but a C4 or CAM plant may need only 200 grams for this purpose. This is one of the reasons halophytes manage to survive in salty water; they simply do not need as much water to begin with.

Halophytes also have an ingenious way of handling the salts they do take up. It is believed that the salts are pumped out of the living part of each plant cell and held in the cell's vacuole or waste storage compartment. To do this – and to thus isolate the harmful salt concentration – takes high osmotic pressures which mean, in turn, high energy expenditures. One of our plant scientists has calculated that some halophytes spend as much energy coping with high salinities as is required to produce one ton of carbohydrates per acre-year. That's the equivalent of a good yield for many cultivated grain crops.

Their unusual need for osmotic energy may also be a clue as to how some of the desert halophytes put up with high levels of solar radiation. If only processes so profligate with energy can keep them alive in highly saline environments, they need those maximum amounts and intensities of sunlight. Conversely, it suggests that if rugged halophytes from coastal deserts, accustomed to salinities even higher than seawater, had a chance at brackish water much lower in salts, they could use much of that energy for more productive functions, such as faster growth rates and heavier crops.

Questing for Halophytes

There are hundreds of different kinds of halophytes around the world, along seacoasts and in estuarine marshes. They are all inundated with seawater, but they vary widely in response to temperature and wet tropical climates. Many receive some fresh water from rain, dew or ground water intrusions and they have lesser requirements for heat. Few of these latter species will survive under harsh desert conditions. Fortuitously, the research station we use on the Gulf of California offers an ideal environment for growing the desired species. There are less than three inches of rain a year, while the annual rate of evaporation is nearly 100 inches. The only ground water is, if anything, saltier than the ocean, and summer temperatures can hit 44 degrees C (111 degrees F).

We started our halophyte research with some seeds and plants from the University of Delaware, USDA, private seed companies and a couple of scientists in Israel. Seeking the more rugged desert species, we made 15 exploring and collecting trips along the bleak coastlines of the northern Gulf of California and the Baja peninsula. Our scientists found a few dozen native species able to thrive in this rugged environment. We ended up with 75 different kinds of halophytes for our first trials.

Our first discovery was that not one of the wild halophytes would germinate in our hypersaline seawater of 40,000 ppm. They had to be started in a little fresh water. This is clearly a survival mechanism, and many desert plants have evolved a similar trick. It guarantees that a new plant won't get started until after a desert rain, when it will have its best chance to stay alive. We found this no real obstacle. For the moment, we germinate halophytes from seed in our greenhouse, using the compact trays developed for forestry seedlings. Extremely little fresh water is required and it is recycled. Once transplanted to the field, the plants are long-lived and may be cropped repeatedly over a course of years before replanting. More importantly, this present freshwater germination can be described as a temporary inconvenience. When we more fully understand this defense mechanism we hope to devise a way to get around it; such short-circuiting of an unwanted natural behavior is now routine in the plant sciences. In addition, we are continually screening thousands of seeds for greater salt tolerance and to thus attack the problem from a second direction.

Another encouraging discovery was that once germinated, a third of all the species could be weaned quickly to seawater. They were then transplanted to the open desert, and after being irrigated with nothing but seawater for a year, the results looked quite good. As Table 1 reveals, 14 different kinds of halophytes had survived; eight of them did very well, and six completed their life cycle by presenting our researchers with viable seed. Meanwhile, laboratory analyses indicated that some of these plants were high in protein and ought to be directly digestible by ruminant animals. (As much as one-half of the weight of the harvested plants was seed, with a protein content as high as 13 percent and comparing favorably with wheat and soybean.)

Some Promising Contenders

In 1979 we chose 11 of the more promising species and germinated tens of thousands of plants in our greenhouses. These were transplanted into 40 plots on a one-hectare (2 ½ acres) experimental farm. Table 2 shows that more than 80 percent of them survived the transition to the open desert and irrigation with only highly saline seawater. And, although these plants were laid out during the hottest month of the year and their initial growth was slow, some astonishingly rapid growth followed. We had planned on making our first harvests from the new plantings in the Spring of 1980. In fact, growth became so rapid we had to begin harvesting nine of the 11 species in December 1979.

These initial harvests from the one-hectare farm gave us some impressive numbers. The best producers did as well or better than many conventional food crops which have to be irrigated with fresh water. The actual range of above-ground dry-weight annual yield we encountered was 895 to 1,365 grams per square meter. This is as good or better than the numbers for such freshwater forage crops as alfalfa (annual dry weight yield of 420 to 940 grams per square meter).

The most promising of the halophytes we are working with include several species of salt bush, which can be valuable forage crops; pickle-weed, which is a gourmet vegetable in England; saltwort, which produces edible roots; and a couple of grain crops such as Palmer's grass. (This latter is the spiky little estuarine plant from the Gulf of California from which the Seris may have harvested seeds to make bread – one of those stories which helped us decide to begin this project. It will be mid-1980 before we will know what grain production may be expected from this grass. Table 3 lists these promising halophytes.

However promising the lab tests may be, the real questions are whether or not animals can and will really eat halophytes, and if so, what will happen to them. We can’t answer those questions yet. The first series of harvests from the one-hectare farm did give us enough seeds and dried plant material for some modest feeding tests with livestock.

Table 1. Survival and growth of halophytes in outdoor plots watered with seawater, July 1978 to May 1979.

Plant	Survival	Final Size*	Flower/Seed
Aeluropis littoralie	-	-	-
Aeluropis macrostackyus	-	-	-
Atriplex barclayana	+	21x50 cm	f/s
Atriplex canescans	+	17x41 cm	-
Atriplex cinerea	+	30x38 cm	f/s
Atriplex glauca	+	19x31 cm	f/s
Atriplex lentiformis	+	32x38 cm	-
Atriplex paula	+	27x18 cm	f/s
Barley (salt tolerant)	-	-	-
Batis maritima	+	runners to 70 cm	f/s
Chenoposium album	-	-	-
Distichlis palmeri	+	runners to 100 cm	-
Distichlis spicata	+	little growth	f(male)
Euchenlaena tomentosa	-	-	-
Ecualyptus spathulata	-	-	-
Nitratia schoberi	+	21x4 cm	f/s
Pucinellia distans	-	-	-
Pucinellia etricta	-	-	-
Pucinellia capillaris	-	-	-
Salicornia europa	+	40x35 cm	f/s
Spartina alterniflora (short form)	+	little growth	-
Spartina alterniflora (tall form)	+	little growth	f
Spartina patens	+	little growth	-
Sporabulua airoides	-	-	-

*height times diameter

Table 2. Above-ground yield (grams dry weight/m^2) of halophytes on 0.61m centers irrigated every 12, 24, and 72 hours with 40 ppt seawater. *Atriplex* spp. were transplanted from greenhouse to 18 desert plots (12.3 x 18.5m) on 23 April 1979. Alternated plants were harvested at t=355 days. *Salicornia europaea* was sown on 16 February and harvested at t = 265 days.

Water Frequency	**Above-Ground**	**Yield**	**(g/m^2)**
(hours)	12	24	72
*Salicornia europaea**	1365	**	**
Batis maritima	1137	**	**
Atriplex linearis	927	1134	245
Atriplex barclayana	901	733	431
Atriplex lentiformis	895	620	230
Atriplex glauca	413	348	130
Atriplex canescans	178	165	111
Atriplex polycarpa	143	61	31
Atriplex rependa	22	15	9

*0.31m centers
**Not determined

Table 3. Halophytes planted in field production trials, April-July 1979.

Species	**Description**	**Economic Potential**
Atriplex barclayana	Perennial spreading	Forage, grain
Atriplex canescans	Perennial erect shrub	Forage, grain
Atriplex glauca	Small prostrate annual	Grain
Atriplex lentiformis	Perennial shrub to 10’ high	Forage, grain
Atriplex mummularia	Perennial erect shrub	Forage
Atriplex patula	Small erect annual	Grain, forage
Atriplex polycarpa	Perennial erect shrub	Grain, forage
Atriplex rependa	Perennial erect shrub	Forage
Distichlis palmeri	Perennial grass with large seeds	Grain, forage
Salicornia europa	Succulent annual	Vegetable crop
Batis maritima	Perennial spreading succulent	Root crop

These preliminary trials are now underway in Hermosillo, Mexico (cattle, swine, poultry) and Tucson, Arizona (goats and smaller farm and laboratory animals); and shrimp feed tests will soon be initiated at the experiment facility on the Gulf of California. We feel pretty confident about the use of halophyte seed crops as a grain feed, so we are really looking to these first trials to indicate how much whole plant material can be mixed into livestock feed without the animals' picking up too much salt. It is believed probably that a livestock diet using a great deal of this plant material would require some sort of preliminary demineralization. Such processes exist.

In addition to the continued growing, harvesting and livestock-testing of our halophytes, some of the larger specimens of the best species have been selected for conservation through vegetative propagation in our greenhouses. Some of these promising species have turned out to be heteromorphic; i.e. the same plant is both male and female. This is most promising, even for plants, because it can enhance and accelerate breeding experiments to develop new strains for high seed production.

An Overdose of Salinity?

We originally figured that salt accumulation in seawater irrigated soil could be a problem unless we devised some way to cope with it. It seemed obvious that if freshwater irrigation in the desert can case a salt build-up in the soil, irrigation by seawater would be likely to make things a lot worse a lot quicker. There are indications in the literature that such might not be the case; however, we had to find out ourselves, so we set up complex and precisely measured soil salinity experiments to run in parallel with the growing trials. Some of the plots were irrigated twice a day with saline effluent from the shrimp production facility. Some plots were irrigated but once a day, and some were irrigated only once every three days. At the same time, we used a variety of techniques, including flood and furrow irrigation. We had some preconceptions about the relative effectiveness of these variables, and more often than not, we were wrong.

Irrigating only once every three days left twice as much salt on the growing surface as irrigating once or twice a day, and plant growth suffered accordingly. Thus, frequent irrigation was indicated. Second, furrow irrigation did not cause any more salt build-up than flood irrigation. Our head plant scientist said he was "astonished" by this. Third, while the seawater from the shrimp raceways had a modest amount of animal fertilizer added to it, it was not enough, we thought, to optimize plant growth. So we tried adding various amounts of other fertilizers to the seawater, and found this did not significantly increase the crop yield. Now we know that such wastewater from an aquaculture facility is in itself a good source of fertilizer for these halophytes.

Soil type is an important consideration in growing halophytes. We obtained very high infiltration rates when the growing medium was 95 percent sand and five percent clay (unsuitable for any other type of agriculture, of course). This means a lot of the salt in the water leaches right on through and below the plant root zone. On the other hand – and typical of the surprises these halophytes have had for us – some of the species we are experimenting with actually grow better in poorly drained soil. This would appear to be of great promise in many inland areas suffering from the problems of saline water.

As a footnote to the experimental results we have just described, it should be mentioned that we also attempted to grow some of the widely publicized salt-resistant barley which other investigators have cultured on seawater in California. The results were not promising. The barley did at least germinate on full-strength seawater, which is more than the wild halophytes did, but all of the seedlings died within two weeks. Concurrent greenhouse trials showed a much higher tolerance of salt for seed germination than for seedling growth, with the latter falling off when salinity approached a fourth that of our hypersaline seawater. This does not necessarily contradict the work done in California. Our scientists were not using exactly the same strain of barley, and seawater irrigation in the West Coast experiments was applied only once a week. It is probably critical that the California trials were performed in a much more humid climate in a higher rainfall area, and seawater irrigation was necessary only weekly.

Back to Solar Energy

Today, with some uneasiness, we find ourselves returning to the ERL's initial preoccupation with solar energy. We know that results are not very promising thus far in the practical use of solar energy, and we knew ahead of time this would happen. To some, solar energy seems to have moral attributes; because nothing impressive seems to be occurring, they see sinister forces at work. To many others who feel less keenly about it the whole concept of "harnessing the sun" seems a little far fetched, and insofar as they are concerned it may be just as well that nothing is happening.

The real problem, of course, is that solar energy has always been oversold. People get angry or disappointed when it does not produce what they have been led to expect from it, and they have been led to expect too much, too soon. In truth, as a separate fuel source, solar is like oil or coal or uranium ore; all of these are free resources. The costs are in collecting, storing, transporting and converting them. Much solar gadgetry always has been and likely always will be appallingly expensive. So the sinister force at work is simply economics. Many solar techniques – hopefully not all – are just too costly.

Like many other researchers with practical experience in this field, we believe that the lowest-cost use of solar energy, for many applications, is, and may continue to be, green plants. Photosynthetic production may not be a highly effective means of solar conversion – the efficiency is only about one percent – but green plants are not expensive, and they don't have to be taught how to do the job.

Green plants are able to do something else as well; they are inherently able to offset, if not actually defeat, some of the higher costs of solar development. Consider the fact that in regions which are not highly industrialized, solar hardware is doubly expensive. There is not only the cost of the hardware itself to be amortized, which is bad enough, but there is also the matter of amortizing the conventional fossil energy required in its manufacture. This can be an insurmountable obstacle in a region which may be limited in both industrial capital and conventional energy and/or may have higher priorities for both.

However, another resource which such capital/energy deficient areas usually have in abundance is people. If a labor surplus is available, the optimum energy development would be something requiring little industrial capital or industrial hardware, but which focuses upon relatively simple, labor-intensive activities.

Planting, growing and harvesting green plants appears to be an ideal solution to this problem. The plant material itself becomes a convenient means of storing energy for subsequent bioconversion processes. Obviously the total investment required is still great and may take many years to amortize. But the more favorable input ratio of human labor to fossil energy would help achieve short- and long-term social objectives as well as help conserve conventional fuel.

Some Geothermal Possibilities

In our view, geothermal energy resources are also a good possibility for parts of the Southwest in general and for agriculture in particular. Apparently Mexico has already moved ahead of us here – it has quietly been building a good-sized geothermal electric plant south of Mexicali without too much fanfare.

It seems that in our part of the Southwest, on both sides of the border, the great fault lines of the continent run south into the Gulf of California. Indeed, this fault zone has helped create the Gulf. There is a lot of heat locked beneath this ruptured, once volcanic region, and not just along the Gulf itself. From the area around Yuma in a band across middle and southern Arizona, there are (or once were) numerous hot springs and hot water wells; one can still find the names on the maps, even where water tables have gone down so much the visible springs have long dried up. Mining companies and ranches have found hot water when they haven’t been looking for it.

Not much has been done with this on the American side of the border, probably because many of our serious geothermalists usually think in terms of high-grade heat, from which electricity can be generated. That’s fine, but even some supplies of low-grade heat, around 100 degrees F, could be a bonanza to desert agriculture and aquaculture. Controlled-environment vegetable or fish or prawn production in a frost area would not require expensive conventional wintertime heating. And such water could also be used for halophyte production, downstream from an animal system, as we are now doing in Mexico. The potential of integrated systems for cash crops and animal fodder is intriguing.

Salinity Inland: Problems and Possibilities

Saline water is not confined to the oceans. Salty (and therefore generally unusable and unused) ground water creates problems on all land masses of the world. An important thing to remember about inland saline water is that there is an abundance of it in the

United States and Mexico. Hydrologists define saline water as any with a salt content in excess of 3,000 ppm. which is about a tenth as salty as seawater, but still three times too salty for conventional agriculture. The known shallow (within a few thousand feet of the surface) saline ground water areas of the United States total at least 250,000 square miles or one-twelfth the area of the entire nation. If one adds to this those regions with "slightly saline" water – 1,000 to 3,000 ppm – two-thirds of the country is included. And in western states like ours, and in much of northern Mexico, many of the areas are virtually unknown, and what are marked off on the maps are simply good guesses.

It is believed that there are more than 18.5 trillion acre-feet of shallow saline ground water in the United States. The "mountain western" states, comparatively short on all kinds of water resources, may contain between two and three trillion acre-feet of this unused resource. It is scattered over about 40,000 square miles.

Within Arizona, known locations of saline water are widely scattered. The largest single chunk of such land is north of the rim country, and the rest of it is spotted throughout the southern half of the state, but mostly in three counties (Maricopa, Pinal and Yuma). It should be noted that in some of these saline locales, conventional agriculture has existed or has been attempted; hence, many fields are now fallow. Indeed, the crop land acreage last reported to be fallow in the three counties was 18.5 percent of the total. (We presume that salinity of ground water is not the only cause of this land idleness, but it is frequently a key factor.)

There is no need to argue further about what might be done with halophytic crops in these inland saline regions. If we can grow useful plants on the seacoast in water of 40,000 ppm, we can certainly do better where the salinity is only one-tenth as great.

The Colorado River Problem

A well-known international dilemma in inland salinity involves the Colorado River. The Colorado and its tributaries are naturally saline from the beginning, leaching minerals from the high country of the southwest and evaporating in the long desert journey to the Gulf of California. Each of the bordering states fights for its share of the river, and there have been near-rebellions over it. California pumps it to Los Angeles for people to drink. The rest of it is used repeatedly for crop irrigation, picking up even more salt. When what is left of the river nears the Mexican border not far above Yuma, salinity is around 900 ppm. By treaty, Mexico is supposed to get 1.5 million acre-feet/year, which is nearly 500 billion gallons. This is a lot of water.

Serious trouble began about 20 years ago, when just before entering Mexico, the river water was diverted once more for a final use in crop irrigation. The salty water became much saltier; salinity at the border went up to 3,000 ppm. Trying to use this to irrigate their own crops, the Mexicans found they were destroying their fields. The Americans put in a diversion canal to drain the worst of the saline water around the Mexicali region, but it was no panacea and the Mexicans remained quite vexed at their loss of land and food production.

Next, the treaty was amended to guarantee to Mexico that its share of the water would be no saltier than the river is upstream from that last big American irrigation district. This means back to 900 ppm again. It also means we have promised something extremely difficult to deliver. Those who promised it had been persuaded that a big desalinization plant on the river could re-purify enough of the river to dilute the rest of it to the desired level.

Large-scale desalting was expensive even before OPEC began to reorder the world economy in the early 1970s. Since then, of course, such processes have come to require even more awesome inputs of capital and energy. Not even the Arabs have put in many units (total world installed desalinization capacity is now about 0.75 million acre-feet), and the Colorado River plant will be the biggest ever built. Some controversy has been inevitable and there have been delays. We understand that present plans call for construction to begin in 1981 and large-scale production to commence in 1984.

About one-third of the projected Colorado River plant capacity will be “blowdown” or wastewater, heavily loaded with the salts removed from the rest of it. The salinity of this wastewater will be about 10,000 ppm or nearly a third as salty as the sea. Something will have to be done with it, and the most obvious something is to canal the blowdown past Mexico’s agricultural country to the Gulf of California, just as some of the saltier-used irrigation water is now handled.

As an alternative, we suggest that the naturally salt-tolerant plants we and our Mexican associates are now domesticating as seed crops and forage and energy sources could be irrigated with the saline blowdown water from the desalting station. Halophyte cash crops and livestock feeds could thus contribute to the total effectiveness of the desalting station and perhaps utilize other salty wastewater as well. It is possible that in at least a portion of this region around the Lower Colorado River and its delta, conventional agriculture as it exists could be replaced with new crops. And in such regions, neither we nor the Mexicans would have to worry about the quality of the water at all.

In Summary

The reader may have recognized by now that there appears to be a cohesiveness to all of the aforementioned efforts and thoughts: a curious interdependence of the various separate potentials in saline aquaculture and agriculture, in the use of low quality desert land, in the identification of useful products to be grown in desert intensities of solar radiation, and in all these particular approaches to the challenges of climate-defensive food production. It may well be that a key to the relative economic success of any of them – i.e. achieving a level of profitability commensurate with desired social objectives, if any – will be the very integration of several or all in any given application. Fig. 4 represents our attempt at a simple diagram expressing this integrated concept with its potential contribution to “climate-proofed” world food supplies.

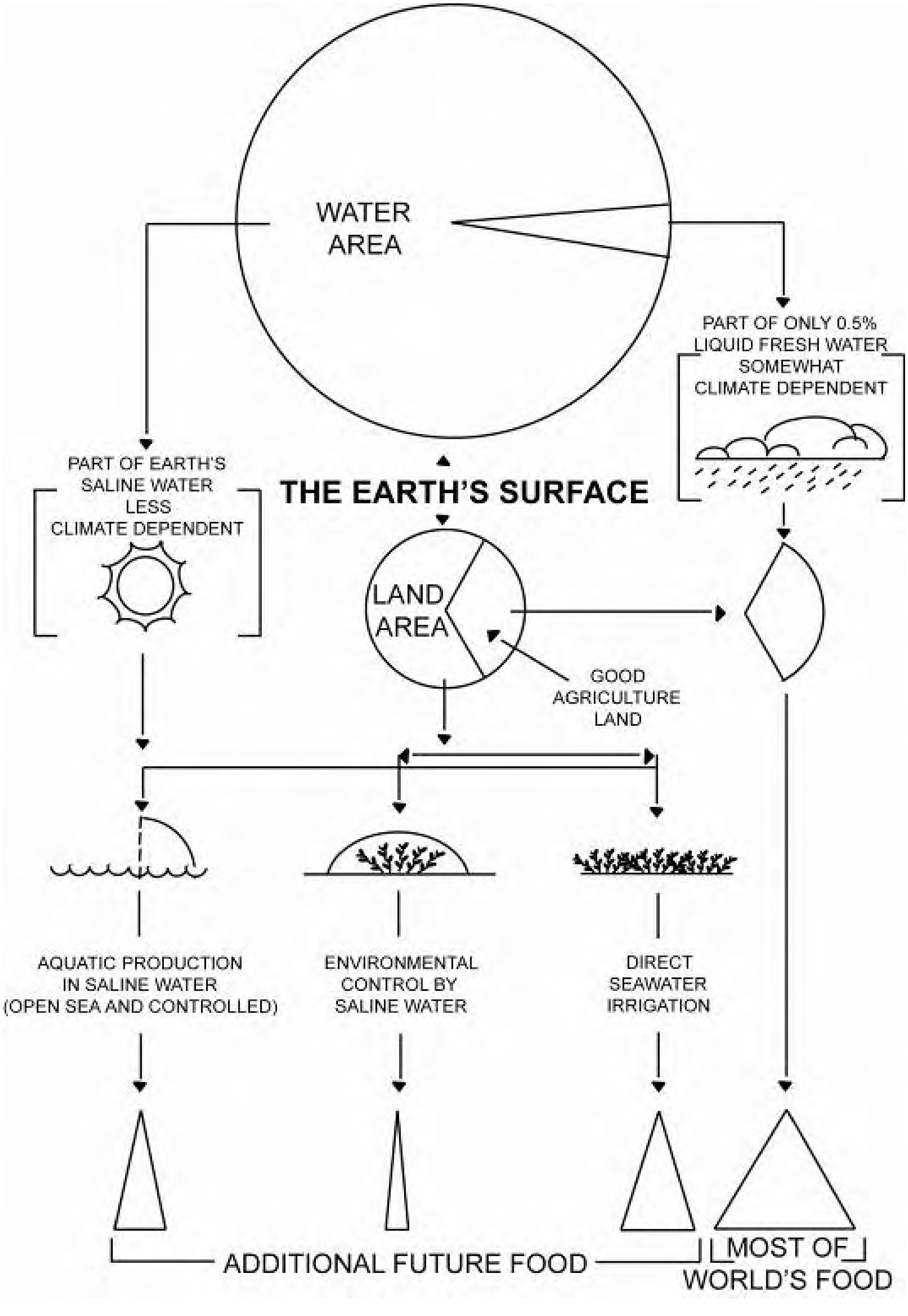


Fig. 4. Conceptual diagram of saline water agriculture in "climate-proofing" food production.

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