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ATMOSPHERIC DYNAMICS AND BIOREGENERATIVE TECHNOLOGIES IN A SOIL-BASED ECOLOGICAL LIFE SUPPORT SYSTEM: INITIAL RESULTS FROM BIOSPHERE 2

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ABSTRACT

Biosphere 2 is the first man-made, soil-based, bioregenerative life support system to be developed and tested. The utilization and amendment of local space resources, e.g. martian soil or lunar regolith, for agricultural and other purposes will be necessary if we are to minimize the requirement for Earth materials in the creation of long-term off-planet bases and habitations. Several of the roles soil plays in Biosphere 2 are 1) for air purification 2) as a key component in created wetland systems to recycle human and animal wastes and 3) as nutrient base for a sustainable agricultural cropping program. Initial results from the Biosphere 2 closure experiment are presented. These include the accelerated cycling rates due to small reservoir sizes, strong diurnal and seasonal fluxes in atmospheric CO_2, an unexpected and continuing decline in atmospheric oxygen, overall maintenance of low levels of trace gases, recycling of waste waters through biological regeneration systems, and operation of an agriculture designed to provide diverse and nutritionally adequate diets for the crew members.

INTRODUCTION

Biosphere 2 is a 1.28 ha, 180,000 m^3 facility near Oracle, Arizona constructed and operated by Space Biospheres Ventures (SBV) for research into the dynamics of ecosystem and biospheric processes. It contains seven major areas — rainforest, savannah, desert, marsh, and ocean ecosystems, agriculture area, and human habitat. It is operated by a crew of eight with a support team on the outside. The structure is virtually airtight (less than 10% air exchange per year at present), and open to energy inputs of sunlight for photosynthesis through its glass and spaceframe structure, and to electrical energy generated outside for power and heating/cooling through an isolated closed loop water supply. It was closed on 26 September 1991 for an initial two-year experiment. The facility has been designed for long-term research, on the order of a hundred years, to facilitate examination of the effects of maturation of ecosystems, stability of the components under varying environmental perturbations, sustainability of genetic populations, and biogeochemical cycles. It is also intended to provide a ground-based facility for developing our understanding of the dynamics of complex life-support systems that will be required for long-term and evolving space habitation /1-6/.

Research prior to Biosphere 2 in bioregenerative life support has either utilized algae/bacterial fluid bioreactors or higher plant crops grown hydroponically. The most advanced of these, the Russian Bios-3 facility, during 4 and 6 month closures, achieved over 90% regeneration of air and water and produced about half the food requirements /7/. To advance beyond this level of life support required developing agricultural systems that could supply total nutrition while maintaining soil fertility, and completely regenerating waste products. The decision was made early in the Biosphere 2 project to develop a soil-based agriculture rather than use one that was hydroponic-based. This was prompted by several considerations:

1. concern about the potential toxic buildup of trace gases in a tightly sealed environment
2. facilitation of waste recycling and return of nutrients to the soil
3. reduction of consumables, such as nutrient solutions for hydroponics
4. similarity to and applicability of research results to Earth's ecosystem and biospheric conditions
5. increased utilization of low-energy, natural mechanisms which have successfully operated over geologic time frames in Earth's biosphere rather than energy-expensive, high technology protocols
6. increased buffering capacities and improved system stability
7. relevance to the potential use of lunar regolith and martian soils in the evolution of off-planet bases cutting the "umbilical cord" to Earth-supplied resources.

RESERVOIR SIZES AND CYCLE RATES IN SYNTHETIC ECOLOGIES

There are key differences in the behavior of small bioregenerative systems from the Earth's environment. Among the foremost differences are the effects the change of scale has on cycling rates. Whether we consider a facility like Bios-3 with a volume of 315 m^3, or the much larger Biosphere 2 with a total volume of about 180,000 m^3, by comparison with the size of Earth's biosphere, they are tiny. Especially important are the drastically different ratios of soil, atmosphere, biomass, and ocean reservoirs that govern the rate of change and cycling of essential biogeochemical elements, such as carbon, nitrogen, and oxygen /8/.

Modelers of synthetic systems have noted: "Without similarly-sized buffers, a bioregenerative life-support system ... for extraterrestrial use will be faced with coordination problems more acute than in any ecosystem found on earth" /9/. Not only must the interactions between elemental cycles be balanced, but the smaller reservoirs and greater concentration of living biomass will result in highly accelerated cycling rates. The potential for concentration of toxic elements in air and water, or for the sequestering of essential elements in soils, sediments, or biomass, becomes far greater in such man-made ecologies.

PROBLEM OF TRACE GAS BUILDUP FROM OUTGASSING IN TIGHTLY SEALED ENVIRONMENTS

The maintenance of good air quality is among the prime challenges posed by these characteristics of closed ecological systems. Analogous problems were revealed with the advent of energy-efficient, tightly sealed buildings which made the "sick building syndrome" the object of considerable research, and illustrated the variety of outgassing processes that may affect air quality. These outgassing compounds may be classified by source of their origin as "technogenic" (from materials and equipment), "biogenic" (from living plants, animals, soils), or "anthropogenic" (from people), though some gases have multiple sources.

There have been problems with the accumulation of trace gases even in spacecraft which have sought to reduce the problem by careful selection of materials. In Apollo, Skylab, and Space Shuttle cabins, for example, 300-400 gases were identified, causing significant concerns about unanticipated reactions among such outgassing products and their effect on the health of the astronauts /10,11/. These air contamination problems occurred in spite of flushing the air volume through the carbon dioxide removal system, and other measures such as "exclusion of material, equipment isolation, absorption of soluble substances on the condensate in humidity-control devices. The results of numerous studies performed in anticipation of a Space Station indicate that these methods would be inadequate for longer missions, larger crews and the anticipated greater variety of equipment" /12/.

The conventional solutions to this problem include filtering methods using charcoal or catalytic oxidation which will require substantial investment of energy and/or expendable parts, such as filters. To solve this problem in Biosphere 2, research was conducted on the use of soil as a medium for the microbial metabolism, and consequent destruction, of trace gases. The population size and functional diversity of soil microbes make them capable of metabolizing an extraordinary range of trace gases that could otherwise pose toxicity problems /13/. "Soil bed reactors" (SBRs) have a history that dates to the beginning of this century, especially in Europe, for the control of odor emissions from industry. For application to bioregenerative life support, SBV conducted research into the development of SBRs compatible with the use of the soil as a growth medium for crops. Tests were also made in laboratory-sized SBRs which demonstrated the efficacy of SBRs to control levels of gases such as methane, carbon monoxide and ethylene in the habitat atmosphere while also supporting plant growth /14/.

Concern about potential trace gas buildup in Biosphere 2 also motivated the design of a continuous air analysis system which monitors CO_2, O_2 and nine of the trace gases targeted as most likely to be of concern. These gases are: CO, H_2S, SO_2, NH_3, NO, NO_x, O_3, CH_4 and total non-methane hydrocarbons /15/.

Air analysis from the first ten months of from Biosphere 2 closure showed the presence of 130 trace gases, both of biogenic and technogenic origin. The entire agricultural cropping area of Biosphere 2 (some 2000 m^2) was constructed so that it can function as an SBR. The system was designed so that the entire air volume of Biosphere 2 can be pumped upwards through the agricultural soil in about one day via some two dozen inlets which distribute it through an air plenum at the bottom of the meter-deep soil bed. To date, trace gases have stayed at safe enough levels that use of the SBR has not been required. This same mechanism of soil metabolism occurs through natural mixing and diffusion of air through the agricultural and wilderness ecosystem soils of Biosphere 2, though at a slower rate than the active pumping used in SBR operation, and may help account for the low level of trace contaminants thus far found in the Biosphere 2 atmosphere.

CARBON DIOXIDE DYNAMICS

The dynamics of major atmospheric components are also quite different in closed ecological systems and highly dependent on each system's size and ratio of components. CO_2 is of primary concern because of its role as a plant nutrient. At lowered concentrations it is capable of slowing plant growth and at sufficiently elevated concentrations it could become toxic to both plants and animals .

Since research in the Biosphere 2 Test Module, a 480 m^3 prototype for Biosphere 2, had revealed strong diurnal and seasonal variations of CO_2 /16/ (Figure 1), it was anticipated that similar dynamics would be seen in Biosphere 2. The distribution of carbon among system compartments in Biosphere 2 differs from its estimated distribution in the Earth's biosphere (Table 1) . To facilitate the maturation of the Biosphere 2 ecosystems over time, soils were installed at depths of up to 5 m in some of the ecosystems patterned on wilderness biomes. As a result, it is estimated that organic carbon in the Biosphere 2 soil is some 540,000 kg. By comparison, living biomass contains some 10,000 kg of carbon, and at a CO_2 concentration of 1500 ppm, there is about 100 kg of carbon in the Biosphere 2 atmosphere. This means that unlike the Earth with an approximate 1:1 ratio of carbon in plant biomass to atmospheric carbon, Biosphere 2 has a ratio of about

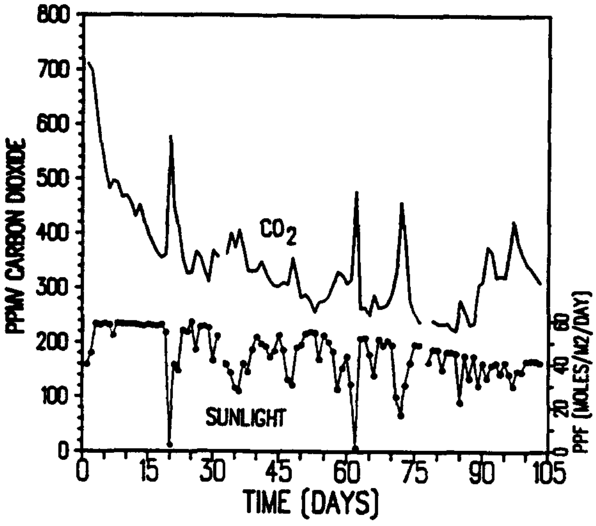

Fig. 1. Test Module daily average CO_2 and daily horizontal light from 25 Jun - 5 Oct 1987. Data missing for days 32 and 77.

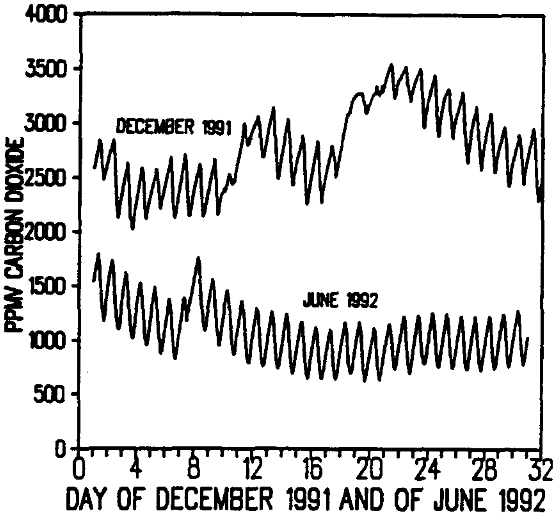

Fig. 2. Biosphere 2 carbon dioxide concentration during a low light month (Dec 1991) and a high light month (Jun 1992). The upsurges of CO_2 coincide with cloudy days. Variations of 500-600 ppm between day and night are evident.

TABLE 1. Comparative Estimated Distribution of Carbon in Earth and in Biosphere 2.

	EARTH*	BIOSPHERE 2
Soil Mineral Component	94.879%	8.9%
Marine Mineral Sediment	5.109%	5.6%
Marine Organic Sediment	**	1.7%
Soil Organic Matter	0.006%	82.3%
Plants	0.003%	1.5%
Atmosphere	0.003%	0.015% (at 1500 ppm)

*From /17/

* * The reference /17/ does not distinguish this compartment.

100:1. The ratio of soil organic carbon to atmosphere is about 2:1 in the biosphere of Earth and over 5000:1 in Biosphere 2 /2/.

These high ratios of soil and living biomass carbon to atmosphere result in a rapid passage of CO_2 through the atmospheric compartment. While mean residence time for atmospheric CO_2 is estimated at about three years /18/, in Biosphere 2 it is four days. CO_2 dynamics also differ because in Biosphere 2 plant growth follows the diurnal light cycle of the project location in southern Arizona. There is a strong fluctuation between daylight hours when CO_2 is strongly drawn down, because of intensive photosynthesis, and night hours when respiration is unchecked, resulting in a rapid rise in CO_2 concentrations. Data from the first twelve months has also shown a strong seasonal variance in CO_2 levels. During the month of December when ambient light fell to its lowest levels (day length 21 December is about 9.5 hours), average CO_2 was some 2466 ppm. By contrast, during June when days were significantly longer (14.5 hours on 21 June) and total light input greatest, CO_2 in the Biosphere 2 atmosphere averaged some 1060 ppm (Figure 2). Outside ambient PPF (Photosynthetic Photon Flux) averaged 16.8 moles/m2/day during December 1991, and 53.7 moles/m2/day during June 1992. On average, 40-50 % of this is received inside Biosphere 2 because of structural shading and glass interception of sunlight. The CO_2 dynamics are so responsive to incident light, that one can see reflected in daily CO_2 graphs the exact time cloud cover passes over Biosphere 2.

Tight coupling of atmospheric CO_2 to plant growth and short residence time of CO_2 in the atmosphere are likely to be even more pronounced in smaller space life-support systems, where the presence of crew members in small volumes will increase the impact of human respiration on atmospheric cycling. The converse problem of lowered plant growth if CO_2 is deficient was revealed in several unmanned experiments conducted in the Biosphere 2 Test Module. There CO_2 levels were sometimes drawn down between 200-300 ppm during peak daylight hours (Figure 1).To buffer these impacts will require the development of techniques to store CO_2 for release when it may be required as a plant nutrient.

Such a system was developed for Biosphere 2 to assist in mitigating seasonal dynamics of CO_2. Designed as a recycling system, the physico-chemical precipitator takes CO_2 from incoming airflow and in a two-step process precipitates calcium carbonate.

1. $CO_2 + 2NaOH \rightarrow Na_2CO_3 + H_2O$
2. $Na_2CO_3 + CaO + H_2O \rightarrow CaCO_3 + 2NaOH$

   To return the CO_2 into the atmosphere, the limestone ($CaCO_3$) can be heated in an oven at 950 C until the $CaCO_3$ disassociates, releasing the CO_2, and regenerating the CaO:
3. $CaCO_3$ (+heat) $\rightarrow CaO + CO_2$

This Biosphere 2 system was scaled such that it can lower CO_2 by about 100 ppm during an operating day. During the first fall/winter period the CO_2 precipitator sequestered about 53,000 moles (equivalent to 9450 ppm in the Biosphere 2 atmosphere) of CO_2. Other strategies which were employed to increase photosynthesis and decrease respiration during the low-light months included lowering night time temperatures, discontinuing composting, minimizing soil disturbance, prolonging active seasons of savannah and desert, pruning areas capable of rapid regrowth (e.g. savannah grasses and ginger family plants in the rainforest) and dry-storing the cut biomass to slow decomposition /19/.

OXYGEN DYNAMICS IN BIOSPHERE 2

While the challenge of maintaining CO_2 at acceptable levels was foreseen, the decline in atmospheric oxygen which has occurred since closure was an unanticipated development. Since closure in September 1991, oxygen has declined from the Earth ambient level of 20.94% to about 16.04% (as of 8 September 1992)(Figure 3). System volume has correspondingly diminished, resulting in an increased percentage of nitrogen. (System volume is variable due to sealed expansion chambers) /20/. About 0.9% oxygen decline is attributable to oxygen sequestered in the calcium carbonate produced by the CO_2 precipitator (after having first reacted with organic carbon to form CO_2).

Several soil reactions may account for the oxygen sequestering, including oxidation of reduced iron, sulfur or nitrogen soil components (e.g. NH_3 or iron pyrite), oxidation of soil organic materials and subsequent formation of $CaCO_3$. A research program which includes examination of oxygen isotopes from Biosphere 2 is investigating which chemical reactions are responsible. Medical examinations have not yet detected an increase in red blood cell count, an early sign of physiological adaptation. At 16.04%, the oxygen partial pressure corresponds to an altitude of about 3,300 m.

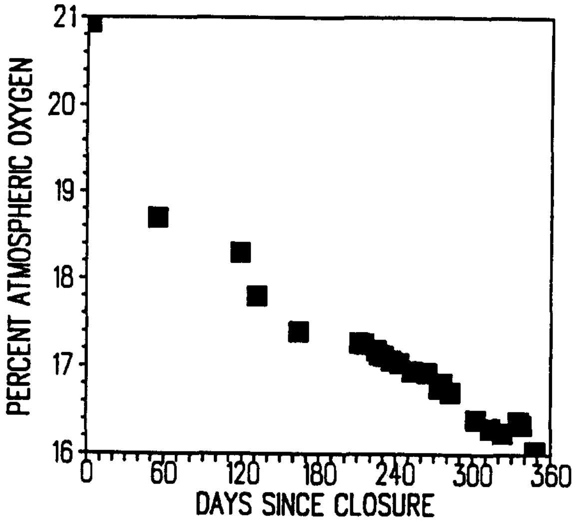

Fig. 3. Biosphere 2 oxygen concentration from 26 Sep 1991 (day 0) to 8 Sep 1992 (day 348).

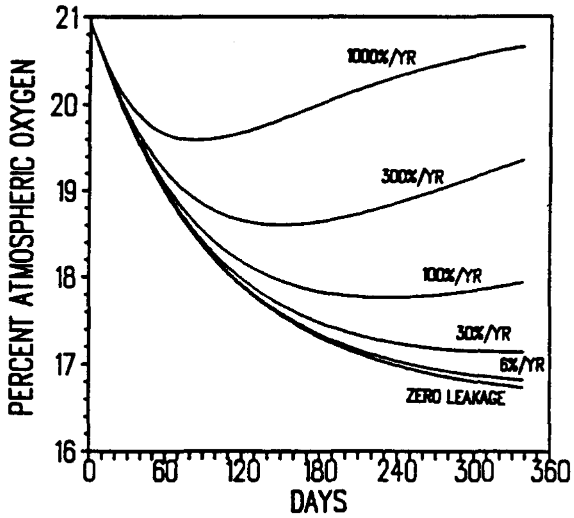

Figure 4. See text. (Note: a leak rate of "1000%/YR" denotes that the average residence time of atmosphere within the hypothetical system is 0.1 year, etc.).

DEGREE OF CLOSURE AND ATMOSPHERIC DYNAMICS

The detection of these interesting oxygen dynamics underscores the importance of sealing in closed ecological systems. Figure 4 illustrates the effect of leakage on the ability to observe atmospheric dynamics. Taking a hypothetical model of oxygen being sequestered at an exponentially decreasing rate (as represented by the "zero leakage" curve), and combining that with the tendency of leakage to restore oxygen concentration toward ambient 20.94%, these curves show the resultant oxygen concentration according to various leak rates. At the higher leak rates, the pattern of oxygen sequestering is seriously obscured. At the 6% per year leak rate estimated for Biosphere 2, the pattern is nearly perfectly intact. Since maintenance of an acceptable atmosphere is one of the prime requirements in evaluating life-support systems, high rates of air exchange will make it difficult to evaluate the dynamics of major and trace gases. In a space environment, the consequences of leakage can be catastrophic, endangering crew or increasing requirements for replacement of air components by energy-consuming production from in-situ resources or transport from Earth.

SBV did extensive technology development for the sealing of Biosphere 2. Previous Russian and U.S. facilities have had leak rates from 1-10% per day. Through the development of a unique method for sealing the glass and spaceframe structure and rigorous testing of those seals and the welded stainless steel liner that seals Biosphere 2 underground, the current leak rate is estimated to be below 10% per year. Leak rate is determined by two independent methods: 1) by observation of two expansion chambers ("lungs"), and 2) by periodic analysis of the decline in concentration of the inert gas SF_6 which was spiked into the Biosphere 2 atmosphere /20/. Detection and sealing of underground leaks through the stainless steel liner is facilitated by a tunnel encircling the foundations from which trace gases can be detected in any of over 200 zones.

Laboratory analyses of air samples are conducted periodically and the leak rate determined by the decline in concentrations of the inert gas SF_6 which was spiked into the Biosphere 2 atmosphere. To facilitate detection and sealing of underground leaks, a system was installed to identify which sector of the stainless steel liner is leaking by trace gas monitoring in an access duct which encircles the structure.

CLOSING THE LOOP ON WASTE RECYCLING

The use of a soil-based system enabled Biosphere 2 to achieve complete regeneration of human and animal waste products /21,22/. This is accomplished by an in-vessel composting system for inedible crop residues and animal manure, and by a created wetlands system for handling human wastes.

The aquatic waste treatment system operates in two steps. Initial decomposition occurs in anaerobic holding tanks. Then batch treatment occurs in aerobic "marsh" lagoons which recirculate the water, exposing it to the aquatic plants (water hyacinth, canna, aquatic grasses and reeds) and their associated microbes which continue the regeneration process. These systems handle all human wastes from the Biosphere 2 habitat (bathrooms, kitchen, laundry) and the wash-down water from the animal barn. The plants used in these systems are fast growing and are periodically cut for fodder or used in composting. After passing through the marsh waste treatment system, the water is added to the irrigation supply for the agricultural crops, thus utilizing the remaining nutrients. A similar marsh wastewater system is employed for any chemical effluent that may occur from internal workshops and laboratories, taking advantage of the fact that aquatic plants will concentrate heavy metals, thus isolating them from soil and water contamination /22/.

An additional advantage of this type of soil-based waste water regeneration for space life-support systems is that the high rates of transpiration of aquatic plants make them valuable sources for quality potable water, which can be condensed from air humidity /23,24/. An important advantage of marsh systems is that they are low maintenance and energy processes, with valuable byproducts. As Schwartzkopf and Cullingford note in a study of technologies for a lunar base:

> Many previous CELSS concepts have incorporated high energy methods of waste degradation such as wet oxidation or super critical wet oxidation. In the process, all of the energy stored in the chemical bonds of the waste materials is lost. By using either bioregenerative technologies or appropriate physiochemical technologies ... some of the chemical bond energy can be provided to the system by converting wastes into low complexity materials which can be used as foodstocks for bacteria, algae or higher plants /25/.

SUSTAINABLE FOOD PRODUCTION IN A SOIL-BASED AGRICULTURE

The requirements of the agricultural system for Biosphere 2 included three major elements: it had to be non-polluting, intensive, and sustainable. SBV and its principal consultant for the agricultural section, the Environmental Research Laboratory of the University of Arizona, began with trials of hydroponic and aeroponic cropping techniques. A variety of reasons underlay the subsequent switch to soil-based agriculture. One, of course, is that hydroponics depends on chemical nutrient solution inputs that would be difficult to produce in a space-setting. Another is that the related question of developing waste recycling for animal and human wastes and inedible portions of crops is much more difficult to resolve without the ability to compost or utilize plant/microbe systems for wastewater regeneration. Composting and marsh wastewater systems are far less energy consumptive than alternatives like wet oxidation or incineration. There are numerous historical examples of sustainable soil agriculture but none thus far of a hydroponic system that can persist without "complex outside additions in the form of fertilizers and pesticides" /26/.

The criterion for a non-polluting agriculture is required because in a small, tightly sealed environment the use of chemicals which might cause toxicity in air or water poses extreme and immediate hazards. Even in the 180,000 m^3 volume of a facility like Biosphere 2, water, soil, and air buffer capacities are so small, that there is no way of introducing pesticides and herbicides without serious health hazards. Thus no conventional biocides are employed. A variety of disease/insect controls are used including introduction of beneficial predator and parasitic insects, safe sprays (sulfur, soap, *Bacillus thuringensis*), use of an extensive polyculture and rotation of crops, selection of resistant varieties and environmental manipulations of temperature/humidity /27,28/.

A nutritionally complete diet is being produced inside Biosphere 2. A wide range of vegetables, grains, starches, and fruit are grown (Table 2). Biosphere 2 maintains semi-tropical temperatures in the agriculture area (18-32 C) permitting both temperate and tropical crops to be grown. The diet includes milk, eggs, meat (from African pygmy goats, a chicken cross between tropical fowl and Japanese silky bantams and Ossabaw feral pygmy pigs), and fish (from Tilapia grown as a component of the rice/azolla paddies). Though the diet includes some animal products, fat is in short supply and peanuts as an additional source of vegetable fat are an important crop. A computer program keeps track of nutrient intake and helps plan forward planting of crops to ensure a balanced diet /1/. The nutrient-adequate and calorie-restricted diet thus far produced has enabled the first studies of human physiological response to the type of diet which in laboratory animal studies has shown marked reduction of factors such as blood cholesterol, blood pressure, and white blood cell counts, along with aging-retardation and lifespan extension /29/. Thus far, similar physiological responses have been seen in the Biosphere 2 crew members /30/.

The entire agricultural area includes some 2000 m^2 and must produce the fodder crops necessary for animal food as well as direct human food crops. The reliance on ambient sunlight, reduced by about a half in passing

Table 2. Human Consumption and Agricultural Production in Biosphere 2.

Average Daily Human Consumption in Biosphere 2 Sept. 1991 to Sept. 1992

	Amount	R.D.A.*	% of R.D.A.
Calories	2125	1700-2500	125 - 85
Protein (grams)	69	58	119
Fat (grams)	29	28	104

** Recommended Daily Allowance*

Total Agricultural Production, Kilograms

VEGETABLES		GRAINS		FRUIT	
Green Beans	8	Rice	196	Apple	1
Beet Greens	273	Sorghum	131	Banana	1024
Beet Roots	308	Wheat	113	Fig	39
Bell Pepper	13			Guava	41
Carrots	88	**STARCHY VEGETABLES**		Kumquat	4
Chili	63			Lemon	10
Cabbage	83	White Potato	198	Lime	4
Cucumber	17	Sweet Potato	1335	Orange	6
Eggplant	155	Malanga	84	Papaya	639
Kale	11	Yam	20		
Lettuce	90			**ANIMAL PRODUCTS**	
Onion	107	**HIGH FAT LEGUME**			
Bok Choy	12			Goat Milk	407
Snow Pea	1	Peanut	24	Goat Meat	8
Squash Seed	8	Soy Bean	14	Pork	35
Summer Squash	287			Fish	10
Swiss Chard	58	**LOW FAT LEGUME**		Eggs	6
Swt. Pot. Greens	64			Chicken Meat	8
Tomato	288	Lab Lab Bean	63		
Winter Squash	261	Pea	15	**GRAND TOTAL**	**6630**

through the structure, also limits productivity and will differ in a space application where artificial light regimes may boost yields. Biosphere 2 marks the first inclusion of animals in a closed system, as well as an expanded variety of crops being harvested and processed. A variety of food-processing equipment is used to minimize labor requirements. Thus far about one-third of crew time has been required for agricultural production, harvest, and food processing.

IMPLICATIONS FOR SPACE APPLICATIONS OF LIFE-SUPPORT SYSTEMS

Some of the design of Biosphere 2 has been geared to optimize its value as a research tool to examine the ecosystem and biospheric functioning of the Earth's planetary biosphere. Certainly, design factors including the radiation environment, ambient atmospheric pressure, and suitability of in-situ materials for structure makes it unlikely that a biospheric system on Mars will look like Biosphere 2. However, the experience that will come from the operations of this ground-based prototype of a permanent complex life and technical infrastructure should yield valuable insights and data about the performance and stability of such systems.

Many of the bioregenerative technologies that the Biosphere 2 project has developed may find application in the initial and near-term life support systems for early Mars exploration and settlement. They will probably evolve from being a backup to physico-chemical life-support systems and partially bioregenerative ones. While the drawback of bioregenerative systems lies in their mass requirements, the bulk of these are components like water, soil, oxygen that can be obtained from martian resources. This will require the development of extraction techniques and bringing initial equipment to Mars.

Biosphere 2 has utilized a soil-based system for the ecological functions that soil microbes play, and its ready completion of recycling steps. However, there will certainly be a place for hydroponic/aeroponic systems for food production in Mars habitations, especially in early stages of development. Banin has indicated that, "on the basis of existing knowledge it is cautiously suggested that from the physical and chemical view points, the martian soil may constitute an appropriate medium for plant growth" /31,32/. Numerous studies suggest that lunar regolith may also be a potential cropping medium with biological and chemical treatment /33/. To supplement the plant nutrients already present in the martian soil will require amendments with organic material and microbial inoculations. To a large extent this may be accomplished by the composting and utilization of waste products from the flight and base crews. Then the types of systems included in Biosphere 2: soil bed reactors, marsh wastewater systems, and sustainable intensive agriculture may be constructed almost entirely from local martian resources.

CONCLUSIONS

The amendment of martian soils and lunar regolith for use in bioregenerative life support systems would make the creation of space habitations far more economical than facilities which require Earth materials. But to date, there has been little experimentation on soil-based technologies in bioregenerative life support. Biosphere 2 is the first soil-based life-support system to be created and operated. Therefore data on its performance will be useful for such systems employed in space. Soil was used to facilitate development of systems for waste recycling, sustainable food production and air purification. Initial results from Biosphere 2 show the increased cycling rates and greater atmospheric fluxes that are predicted for closed ecological life support systems. The distribution of highly active carbon in soil organics, air and living biomass have dramatically differing ratios than are found in Earth's environment. This affects mean residence time of CO_2 in the atmosphere, resulting in a decrease from three years to four days, and the balance of photosynthesis/respiration in the system. Biosphere 2 has shown during its first twelve months of operation both strong diurnal and seasonal variations in CO_2. Oxygen has declined from 20.94% to 16.04%. A wide variety of trace gases has been detected in Biosphere 2, but their concentrations have not required operation of the soil bed reactor system. The agricultural system has been producing a complete and varied diet for the crew. Waste recycling via composting and marsh treatment systems have been operating to return nutrients to the agricultural soil thus making it possible that sustainable levels of soil fertility may be maintained.

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