POTENTIAL BENEFITS OF A VEGETARIAN DIET IN SPACE SETTLEMENTS*

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Abstract

The paper discusses how a vegetarian diet might be beneficial to people living on the moon, free-space settlements, or other planets. The argument is made from a logistical perspective. Some medical results are cited so as to suggest other ramifications of continuing with a vegetarian diet. This paper reviews four topics: water usage, job performance and oxygen use, the human body's calcium balance, and the health benefits of miso, a soybean paste. The combined results of not eating meat or transporting animals would be less water required for a mission, astronauts with a better state of health, and mitigated body damage due to weightlessness and radiation exposure.

Introduction

As many researchers in the field of space development know what works on earth does not necessarily work in space. On earth most humans over the centuries have not had to be to concerned about resource management, with the exception of modern-day humans. What ever natural materials or land was close by was used. Efficiency not being a concern. It is the intent of this paper to consider what and possibly how humans eat on other space bodies will not emulate what is know on earth. Chemically defined diets, providing only essential nutrients in a liquid form, have been investigated for astronaut use.[8] Dufour further adds that such an extreme diet is no longer being seriously considered for use in healthy individuals.[8] From a resource standpoint these diets would not be practical because of the amount of discarding involved to produce the needed chemicals. When examining sustaining life for extended periods away from the earth, the designers of the enclosed habitat will implement the most efficient, healthiest, and cost effective way to exist. Living as a vegetarian will accomplish these parameters. The production inefficiency of meat is the basic premise why a meat centered diet would not be practical or cost effective on the moon. Lappe compares the pounds of soy and grain needed to produce one pound of meat products. These ratios are beef 16:1, pork 6:1, turkey 4:1, eggs 3:1, and chicken 3:1.[27:70] These ratios are initial evidence that suggest from a resource standpoint having meat as part of the diet is not practical. What specifically these non-earth humans will be eating is being researched by nine graduate students at Purdue University. NASA has provided a grant to the NASA Special Center of Research and Training in Bioregenerative Life Support (NSCORT), which is currently in its third year.[33] In modeling the biological mechanism, scientists have discovered that the biological mechanisms on earth, such as gravity's affect on the body, do not hold true in space. The same may also be expected for many of the concepts and mechanisms implemented to explore space.

Basic Human Needs

Humanity's basic needs of water, food, and oxygen are closely tied together when confined to a finite spaces. Water is also used to grow the food, and the food in turn through photosynthesis takes in CO_2

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given off by humans and converts it into oxygen. The oxygen is finally returned to the human body to sustain its life. This is a simplified explanation of the process in a human closed loop system.

How can these basic needs be adjusted to meet the design parameters proposed? With water: introduce a agricultural system that requires little water to initialize, to sustain, and to use in processing the final product. With food: provide foods that are efficient suppliers of nutrients Most animals are only approximately 10% efficient in the food energy produced for the calories they consumed.[13,33,39] Oxygen: support the body's ability to utilize oxygen by introducing foods that are low in fat or foods that supply nutrients that increase the oxygen absorption in the body.

Several sources provide analyses of what is required for human basic needs in space.[7,21,43,42] Of these sources Dalton and Hohmann give the best analysis based on calorie expenditure and protein, fat, and carbohydrate needs.[7] Unfortunately, it is based on a diet of the late 1960's when high protein diets were in vogue. Johnson and Holbrow show the mass balance for various foods while performing different activities.[21] The data, though, are also based on an earlier diet philosophy, with added analyses in terms of the carbon, hydrogen, oxygen, and nitrogen content. This knowledge is helpful for assessing chemical reactions when designing a totally enclosed food/waste cycle or agricultural facility.[9] Table 1 gives Schwartzkopf's mass in/out flow figures for one human for one day.[42:1223]

Table 1. Total Input and Output of One Person, One Day, in Space

INPUTS			
	lbs	kg	
	1.84	0.837	Oxygen
	1.36	0.618	Food (dry weight)
	1.10	0.5	Water in food
	1.58	0.718	Food preparation Water
	4.10	1.86	Drinking Water
	4.01	1.82	Hand/Face Wash Water
	8.03	3.64	Shower Water
	2.51	1.14	Clothing
	27.58	12.5	Clothes Wash Water
TOTAL MASS:			
	52.11	23.62	
OUTPUTS			
	lbs	kg	
	2.20	1	Carbon Dioxide
	4.04	1.83	Respiration/Perspiration Water
	3.33	1.51	Urine
	0.20	0.09	Feces Water
	0.04	0.017	Sweat Solids
	0.13	0.06	Urine Solids
	0.07	0.033	Feces Solids
	12.04	5.46	Hygiene Water
	2.51	1.14	Clothing
	27.58	12.5	Clothes Wash Water
TOTAL MASS:			
	52.11	23.62	

This table depicts how efficient the scientists at NASA have become in providing water and food in a semi closed loop system. However when viewing the list of meal items, what is not evident is what growing needs and water usage were needed to cultivate the animals and plants. There are 75 food items available from which a current astronaut can select their meal, with over a third from animal sources.[35,36] No current astronaut claims to be a vegetarian, and most astronauts complain that there is not enough meat.[26] If these items are to be used in a self contained facility then their growing needs will have to be compared for water usage efficiency.

In over 30 years of manned spaceflight, one aspect of the space program, namely meals, has seen little change. Providing food for the astronauts means mostly freeze-dried or pureed lightweight sealed pouches. The variety and quality of the meals has improved with each space program.[35] Human excrement waste was a big concern during the 1960s, so the astronauts of the Apollo program prepared for their journeys by eating a "low residue" diet for several weeks that included steak at almost every meal.[17] Evidence now shows that such a diet, consistently maintained, possibly promotes some forms of cancer.[40]

The principal argument against this form of diet is that it lacks the necessary components to sustain required work levels and protein.[40] Burning calories give a human being the energy to perform work. NASA astronauts chose their meals, but it must provide at least 2,800 kcal/day.[35] This is a consistent figure throughout the literature reviewed.[21,28] However, currently NASA has established the calorie intake at 3,000 kcal/day [25,26], which fluctuates for each astronaut.[26,8] The United States cultural trend in the last two decades has shifted from providing most of the calories from fats and proteins to carbohydrates. Vegetables, grains, and fruits are high in carbohydrates and low in fat. Supplying enough food should provide the calories for the workload. Another factor is the astronauts' tight schedule. The mission schedules are designed to maximize the astronauts working shifts. This is partly due to NASA's large financial investment. The optimum expectation would be for them to eat with little resting time afterwards. This would not be accomplished on a meat centered diet because meat proteins take longer to digest (i.e. 6-12 hours, compared to vegetables, 4 hours). The panel that reviewed the nutritional requirements of the Space Station Freedom Crew suggest for further research the recording of meals times relative to the exercise period.[25] The debilitating outcome of a poor food choice may be that most of a person's blood is surrounding the stomach helping in the digestion of food. Evidence of this argument is apparent in that constipation is a result of the present eating habits and conditions of space shuttle flights.[26]

The concern that some people have with eating a vegetarian diet is its perceived lack of protein. The actual daily quantity required by humans is a small amount. In Haas' book, *Eat to Win,* he outlines that the daily protein intake should be no more than the size of a 6 1/2 oz (184 g) can of tuna.[14] Dufour [8] cites a more precise measurement: 2.83×10^{-2} oz (.8 g) per 2.2 lb (kg) body weight per day. This is equivalent to 2 oz (56 g) of protein per day for a 155 lb (70 kg) man. It is not simply a matter of suppling amino acids as it is important to have the right balance.[8] Robbins[40] sites the work of Frances Lappe that is documented in her 1960 book[27], *Diet for a Small Planet.* She set out to prove the wastefulness of a meat-centered diet. She discovered that combining plant foods in certain ways produces proteins which more closely approximate the ideal, an egg. She considered eggs the ultimate standard because of their amino acid spectrum.[27,40] Dufour agrees with this finding and adds that soybean protein provides all the essential amino acids.[8]

Food Production in Space

The question then arises "Can vegetables be grown in space?" Fielder and Leggett have written at least three articles on designing agricultural systems.[9,10,11] The design of the lunar base may require reduced pressures in the agricultural areas. It may be possible to grow vegetables at very low pressure. Rocco Mancinelli, a researcher at NASA-Ames, grew wheat at 1.02 psi (70 millibar) total pressure, but because of size constraints the test only lasted 7 days.[29] More research is needed.[29] The pressure must be high enough for either pollinating insects to fly or for pollinating fans to operate. The literature offers no pressure limits. Whether insects are necessary is a topic for further debate. The Biosphere II project in Arizona, may provide answers to some of these questions. The designers of Biosphere II decided to use chickens, small pigs, and fish. Although dietary concerns were a part of the design for the eight person experiment team, the real mission of this project is to model earth's present ecosystem.[44,1] NASA is experimenting with wheat, soy, white potato, and lettuce in the Controlled Ecological Life Support System (CELSS).[13,34] The results so far have been that these plants grow faster in closed environment.

Water Supply Challenges

Water presents the most difficult logistical challenge with living in a sustainable closed loop system. If hydrogen and oxygen are not present in any form at the final location, then the total mass of the water must be shipped. At the cost to transport approximately 50 lbs (22.72 kg) per person, such effort can be expensive. This does not include a factor of safety in the event that the filtering system fails or the water is contaminated. This factor of safety and the water needed to grow the few pounds of food consumed each day will be added for a permanent self-sufficient mission.

From a water stand point which is the best eating life style to have? Robbins documents the water consumption applicable to three life-styles on earth. "To produce a day's food for one meat-eater takes over 4,000 gallons (15.14 m^3); for a lacto-ovo vegetarian, only 1,200 gallons (4.54 m^3); and, for pure vegetarian, only 300 gallons (1.136 m^3)." [40:367, 27,6] Borgstrom[6] states that it takes 2,500 gallons (9.46 m^3) of water to produce 1 lb (453 g) of beef.[27] This is a controversial figure because of the current debate in the United States over the practices of cattle producers. The figure quoted from the National Cattlemen's Association (NCA) is 440 gallons (1.67 m^3).[37] This is based on research from Dr. J.L. Beckett and Dr. J. W. Oltjen from UC Davis.[5] This figure maybe skewed not to include the water from rainfall in certain parts of the country, since the research examines and averages the practice's of cattle rancher for the whole United States. Also the total water consumed is possibly divided by a 1,100 lb (498.3 kg) steer and not 600 lb (272 kg) of usable beef. More precise than the 2,500 figure is a figure of 2,464 gallons (9.32 m^3) cited by the Water Education Foundation, Sacramento, California. This figure examines the water usage in California, which experiences many droughts and so the water is monitored through purchases by agricultural groups. Since there is no rainfall on the moon, the correct figure may probably be close to the 2,500 gallons (9.46 m^3) figure.

Here is an analysis of the amount of

water that may be required. Steers are pure vegetarians. It is plausible to assume that the water consumption for its food is at least 300 gallons per day. A steer drinks on average 11.5 gallons of water per day.[37] The average life of a steer ready for slaughter is 2 years (especially if it is fed hormones).[12] The total water to grow the food to raise the steer is 219,000 gallons (828.92 m^3). The life time drinking water required is 8,400 gallons (31.79 m^3) [7,300 gallons provided by NCA[37]]. The total, not including water used in slaughter clean up, is 227,400 gallons (860.71 m^3). For 600 lbs (272 kg) of usable beef out of a 1,100 lb (498.3 kg) steer this results in 380 gallons (1.45 m^3) per lb (453 g) of beef. In terms of putting a steer on the moon, the total water consumed over its lifetime could be much less. With the use of water recycling equipment the exact number would be between 320+ gallons (1.44 m^3) and 227,400 gallons (860.71 m^3). Using data from a five year research study on the growth of ruminants [19], the total water stored in a steer during its lifetime is approxiamately 70 gallons (0.265 m^3). These calculations requires further investigation, especially to understand the water stored in the plant growth for the selected feed material.

Closing the water loop system is crucial for extending human presence because of the large quantities required per person.[43] The perceived challenge is how to purify the water so it can be reused. While nature does this filtering quite well, artificial systems seem to be less effective. This is evidenced by the amount of chlorine needed to kill harmful bacteria in city water systems. Possibly gaps in the ecosystem occurred as western cultures developed large cities and large scale farming, so the answer may lie in the farming practices. A culture in the Pakistani mountains, for example, recycles all food scraps and human wastes.[46] They are the people of Hunza. They also eat very little meat. Their recycling procedure produces a very rich soil. With all this open handling of material, there is little sickness. Why? One possible reason is that they eat foods rich in minerals that prevent illness.[46] The foods contain nutrients because the Hunza have kept in balance with their ecosystem rather than attempting to control it. This approach may be valuable to a successful long term lunar mission.

Job Performance and Oxygen Usage

Crucial to the success of a lunar mission is how well the inhabitants perform their jobs. Robbins[40] offers examples of top athletes who are vegetarians to illustrate how diet affects performance. Edwin Moses and Murray Rose are two examples listed. Another vegetarian Robbins refers to is Dave Scott.[40] He has been recognized in the past as the greatest triathlete in the world and has won Hawaii's Ironman Triathlon a record four times. While nobody will be expected to compete in a triathlon on the moon, their body will feel the impact of unusual conditions like weightlessness and varying pressures. These conditions can cause some fatigue. For the estimated cost of sending a person to the moon for one year, $2.2 million [1989 figure][43], it is important that those persons operate at top efficiency.

One aspect lacking in a vegan diet, a diet with no animal products, is the particular forms of fat associated with dairy products and red meat. Research over the last 10 years increasingly suggests that a diet high in saturated fat causes several illness such as heart disease.[8] Many sports trainers have recognized how counterproductive such a diet is and offers diets with non-fat or low fat dairy products.[14,30] Medical researchers have determined why oils and fats, most of which are known as triglycerides, do cause the human body to not perform well. On one level excess triglycerides act like glue in the blood stream. This may cause red blood cells to stick together, impeding the oxygen delivery system.[30] The other drain on the whole closed loop system occurs when calories are burned. The calories of energy given off by fat require three times as much oxygen compared to carbohydrates and proteins due to the number of reduced chemical bonds that must be filled.[45] The point here is not to remove fat from the diet. A good balance of monosaturated, saturated, and polyunsaturated fats helps maintain a healthily level of useful body fat. NASA currently uses the three oil ratio of 1.5-2:1:1, respectively.[25,26] This can be met with a few tablespoons of oil daily [8] - safflower, sunflower, or canola. Most animal meat, excluding certain types of fish, contains higher levels of saturated fats.

Calcium Loss Prevention

Of the three most severe health hazards to living in space, bone-thinning is probably the least understood, in terms of data, and the most difficult to prevent.[43] "Understanding how bone strength, mass and mineral content decrease as a result of spaceflight is an ongoing area of research."[34:20] Bone-thinning occurs when the calcium balance in the body is disturbed. This balance regulates the calcium gain and loss in the bones when calcium is lacking in the diet. NASA doctors noticed, by monitoring astronauts exposed to a zero-gravity environment, a typical 10% bone loss and a high volume of calcium excreted in urine and feces.[43] The solution during Skylab was to drink excess milk and eat more cheese. It did not work.[43] Shipman describes the problem as bone cells being destroyed at a high rate and urine analysis validated this prognosis.[43] The minerals calcium, phosphorus, and magnesium must be present in certain ratios for optimal health: calcium to phosphorus 1:1 and calcium to magnesium 2:1. [8] Robbins'[40] research into vegetarian diets may provide a solution to correct this loss. Table 2 lists five independent studies performed from 1972 to 1984. These studies tried to find a correlation between protein intake and calcium supplies in the body. On the chart, a positive calcium balance

Table 2. Correlation Between Excess Protein and Calcium Deficiency

Study No.	Calcium Intake (mg.)	Change in Calcium Balance With a Low-Protein Diet	Change in Calcium Balance With a High-Protein Diet
1	500	+31	-120
2	500	+24	-116
3	800	+12	-85
4	1400	+10	-84
5	1400	+20	-65
AVERAGE	920	+19	-94

Study references: #1 [2], #2 [15], #3 [47], #4 [20], and #5 [28].

[Data as per McDougall [32]]

means that the bones are not losing calcium, so that the calcium in the blood can be used for vital body functions. A negative balance means that the bones are losing calcium, signaling the onset of osteoporosis.[40] World-wide studies have indicated that the greater the intake of protein the more severe the condition of osteoporosis.[40] A panel of doctors and nutritionists reviewing astronaut food requirements agree with these findings, stating, "A high protein intake may slow muscle loss, but increases calcium loss." 25:1

Medical Benefits of Miso

Miso, a soybean paste, as been eaten for centuries in Japan and other Asian countries. However, only recently have medical researchers been able to demonstrate its beneficial properties for the prevention of cancer. Four recent articles document scientific tests results that conclude miso's potential benefit for maintaining a healthy body.[3,4,41,48] The tests were not consistent in recommending that increasing miso consumption would significantly prevent or mitigate various forms of cancer.

The research tests reported in these articles approached finding benefits differently. All the results are positive for the application in space. Two of the studies examined how miso interacted with cancer. Baggott *et al* [4] introduced mammary carcinogens to rats and the results showed that the miso fed animals did have a trend toward fewer cancers per animal compared to a control group, but the difference was not statistically significant. Watanabe *et al* [48] performed work that is more relevant to space travel. They X-irradiated rats and then fed them miso and other control substances. Their findings indicate that miso was not effective in preventing the generation of precursor lesions that lead to cancer. The findings surprisingly showed that a diet consisting of 10% NaCl (salt) decreased the occurrence of lesions. Santiago *et al* [41] mixed miso with various free radicals and discovered that miso effectively scavenged the free radicals. Their conclusion is that miso acts as an antioxidant. Asahara *et al* [3] isolated three microorganisms from miso and tested their ability to bind onto mutagenic cells. Two types of cells were experimented with. The results with one type was that the binding ability and antimutagenicity of cell walls was very high. Most microorganism strains had no effective activity against the cells of the other type.

The Resulting Argument for a Vegetarian Diet

Water, as one of the largest components of the agricultural system, has not been found on the moon. Since water supply is such a critical issue it makes sense, from this viewpoint, that a vegetarian diet incorporated into the design holds out the possibility that a non-meat diet may save a significant amount of this precious off earth resource.

Designing an agricultural system that requires less space, since housing animals and the food to feed are not present, will ultimately reduce the cost of the settlement. Add to this, the peak performance ability of the space settlers to perform their job and possibly more costs are not accrued. Finally, the introduction of some foods may help prevent serious diseases.

Conclusions

A possible conclusion from contemporary research is that introducing a vegetarian diet on space missions may reduce bone loss and speed recovery after the mission. Therefore, if the introduction of animal products is for reasons of personal or cultural preference, the added disability of providing such meals may out weigh these subjective preferences.

From the standpoint of designing a food loop, a water loop, and a waste loop, while increasing human energy efficiency, implementing a vegan life-style for the inhabitants of space settlements is a logical decision.

Recommendations for Future Research

Further investigation should be conducted to compare the water recycling needs of various foods derived from animals and plants. What is the lag time for the water stored in a food source until it is cultivated?

A comprehensive study should be conducted on the selected foods for space settlements. This study should tabulate for each food the required amount of the following resources: water, lighting, power, atmosphere, agricultural space, and nutritional value. This information should help in the design of an efficient space settlement.

BIBLIOGRAPHY

1. Allen, John, Mark Nelson *Space Biospheres*, The Biosphere Catalogue, Tango Parrish Snyder (ed.) (Fort Worth, TX: Synergetic Press, 1985), pp. 135-142.

2. Anad, C. *Effect of Protein Intake on Calcium Balance of Young Men Given 500 Mg Calcium Daily*, Journal of Nutrition, 104:695, 1974.

3. Asahara, Naomi, Xue Bin Zhang, and Yoshiyuki Ohata *Antimutagenicity and Mutagen-Binding Activation of Mutagenic Pyrolyzates by Microorganisms Isolated from Japanese Miso*, Journal of Science, Food, and Agriculture, v 58, pp. 395-401, 1992.

4. Baggott, Joseph E., Taisun Ha, William H. Vaughn, M. Margaret Juliana, J. Michael Hardin, and Clinton J. Grubbs *Effect of Miso (Japanese Soybean Paste) and NaCl on DMBA-Induced Rat Mammary Tumors*, Nutrition and Cancer, v 14 n 2, pp. 104-109, 1990.

5. Beckett, Dr. J.L., and Dr. J. W. Oltjen *Estimation of the Water Requirements for Beef Cattle Production in the United States*, University of California, Davis, April 1992.

6. Borgstrom, Georg *Impacts on the Demand for and Quality of Land and Water*, presentation to the Annual Meeting of the American Association for the Advancement of Science (AAAS), 1981, then visiting professor at Michigan State University.

7. Dalton, Charles, and Edward Hohmann eds. *Conceptual Design of a Lunar Colony*, NASA/ASEE Systems Design Institute conducted at University of Houston, MSC, and Rice University, NASA Grant NGT 44-005-114, 497 pp., 1972.

8. Dufour, Patricia A. *Nutritional Models for Space Travel From Chemically Defined Diets*, Prepared for NASA under Contract NASW-3165, NASA Contractor Report 3850, 1984.

9. Fielder, Judith, Nickolaus Leggett *A Second Generation Lunar Agricultural System*, Journal of the British Interplanetary Society, v 41, 1988, pp. 263-268.

10. Fielder, Judith, Nickolaus Leggett *Lunar Agricultural Requirements Definition*, Engineering, Construction, and Operations in Space: Proceedings of Space 88. Published by ASCE, New York, NY, pp. 344-351, 1988.

11. Fielder, Judith, Nickolaus Leggett *A Second Generation Lunar Agricultural System*, Engineering, Construction, and Operations in Space: Proceedings of Space 88. Published by ASCE, New York, NY, pp. 1233-1240, 1988.

12. Fowler, N. G. *Beef and Dairy Management and Production* (London: Hutchinson Educational Ltd., 1968) 310 pp.

13. Garland, Jay *Personal phone conversation, April 1993,* CELSS project personnel, NASA Kennedy Space Center, FL.

14. Haas, Robert *Eat to Win* (Canada: McClelland and Stewart, Ltd., 1983) 267 pp.

15. Hegsted, M. *Urinary Calcium and Calcium Balance in Young Men as Affected by Level of Protein and Phosphorous Intake,* Journal of Nutrition, 111:53, 1981.

16. Heiken, Grant, David Vaniman, Bevan M. French, eds. *Lunar Sourcebook, A User's Guide to the Moon* (New York: Cambridge University Press, 1991) 736 pp.

17. Hurt, Harry III *For All Mankind* (New York: Atlantic Press, 1988) 352 pp.

18. IAA *Ad Hoc* Committee "Return to the Moon," *The Case for an International Lunar Base,* Acta Astronautica v 17 n 5, pp. 463-489 (H. Hermann Keolle, Chairman, submitted this proposal to the International Academy of Astronautics compiled on 11 October, 1987).

19. International Atomic Energy Agency, *Use of Tritiated Water in Studies of Production and Adaptation in Ruminants* (Vienna, Austria: I.A.E.A, 1982), 18 papers presented, 218pp.

20. Johnson, N. *Effect of Level of Protein Intake on Urinary and Fecal Calcium and Calcium Retention of Young Adult Males,* Journal of Nutrition, 100:1425, 1970.

21. Johnson, Richard D., Charles Holbrow eds. *Space Settlements: A Design Study,* NASA SP-413, Scientific and Technical Information Office, Washington D.C., 185 pp. (1975 Summer Faculty Fellowship Program in Engineering Systems Design) 1977.

22. Johnson, Stewart W., and R. S. Leonard *Evolution of Concepts for Lunar Bases,* Lunar Bases and Space Activities of the 21st Century, Wendell Mendell, ed. (Houston, TX: Lunar and Planetary Institute, 1985) pp. 47-56.

23. Jones, Eric M. *Working on the Moon: The Apollo Experience,* Engineering, Construction, and Operations in Space II: Proceedings of Space 90. Part II. Published by ASCE, Boston, MA, pp. 1423-1432, 1990.

24. Klassi, Jason *Comparisons Between Space Facilities and Earth-Based Analogs,* Engineering, Construction, and Operations in Space: Proceedings of Space 88. Published by ASCE, New York, NY, pp. 882-891, 1988.

25. Lane, Dr. Helen, Barbara L. Rice, and Christine F. Wogan *Nutritional Requirements for Space Station Freedom Crews,* Report of a panel discussion held at the Lunar and Planetary Institute, Houston, TX, February 4-5, 1991, NASA Conference Publication 3146, 1992.

26. Lane, Dr. Helen *Personal phone conversation with an assistant to Dr. Lane,* Space and Life Sciences Directorate, Biomedical Operations Research Branch, NASA JSC, TX, 1993.

27. Lappe, Frances Moore *Diet For a Small Planet,* (New York, NY:Ballentine Books, 1st. edition 1971) 479 pp., 1991 edition.

28. Linkswiller, W. *Calcium Retention of Young Adult Males As affected by Level of Protein and of Calcium Intake,* Trans New York Academy of Science, 36:333, 1974.

29. Mackenzie, Bruce A. *Homesteading Mars,* Engineering, Construction, and Operations in Space: Proceedings of Space 88. Published by ASCE, New York, NY, pp. 465-479, 1988.

30. Mannerberg, Don, M.D. *Aerobic Nutrition* (New York: Elsevier-Dutton Publishing Co., Inc., 1981) 337 pp.

31. McDonough, Thomas R. *SPACE The Next Twenty-Five Years,* Revised and Updated (New York: Wiley & Sons, Inc., 1986) 256 pp., 1989 edition.

32. McDougall, Dr. John *McDougall's Medicine* (New York: New Century Publishers, 1985)

33. Mitchell, Dr. Cary *Phone conversation in April 1993,* NASA Special Center of Research and Training in Bioregenerative Life Support (NSCORT), project director, Purdue University, Indiana.

34. NASA *Life Science Report,* Space Life Sciences Symposium, Washington DC, June 1987, NASA Office of Space Science and Applications Life Sciences Division, NAS 1.62/3:1987, 1987.

35. NASA Facts 133 *Food for Space Flight,* Educational Publication of NASA, NF-133 6-82, 1982.

36. NASA Facts 150 *Space Shuttle Food Systems,* Educational Publication of NASA, NF-150/1-86, 1986.

37. NCA *Industry Facts: Water Use/Water Quality/ Wetlands,* The National Cattlemen's Association, Cattle and Beef Handbook, Denver, CO., 1992.

38. Polette, Tom, Larry Toups *A Phased Approach to Lunar-Based Agriculture,* Engineering, Construction, and Operations in Space: Proceedings of Space 88. Published by ASCE, New York, NY, pp. 287-297, 1988.

39. Rifkin, Jeremy *Beyond Beef* (New York, NY: the Penguin Group, 1992) 353 pp.

40. Robbins, John *Diet for a New America* (Walpole, NH: Stillpoint Publishing, 1987) 421 pp.

41. Santiago, Librado A., Midori Hiramatsu, and Akitane Mori *Japanese Soybean Paste Miso Scavenges Free Radicals and Inhibits Lipid Peroxidation,* Journal of Nutritional Science and Vitaminology, v 38, n 2, pp. 297-304, June 1, 1992.

42. Schwartzkopf, Steven H., Hatice S. Cullingford *Conceptual Design For a Lunar-Base CELSS,* Engineering, Construction, and Operations in Space II: Proceedings of Space 90. Part II. Published by ASCE, Boston, MA, pp. 1216-1225, 1990.

43. Shipman, Harry L. *Humans in Space* (New York: Plenum Press, 1989) 350 pp.

44. Snyder, Parrish T. (ed) *The Biosphere Catalogue,* (Tucson, A: Synergetic Press, 1985).

45. Stokes, G. B. *Nutrients, Energy Content,* Encyclopedia of Human Biology, Academic Press, Inc., Volume 5, pp. 471-476, 1991.

46. Taylor, Renee *Hunza Health Secrets for Long Life and Happiness* (New Canaan, Connecticut: Pivot Health Books, 1964) 186 pp., 1978 edition.

47. Walker, R. (1972) *Calcium Retention in the Adult Human Male As Affected by Protein Intake,* Journal of Nutrition, 102:1297, 1972.

48. Watanabe, Hiromitsu, Taro Okamoto, Tadateru Takahashi, Peter Osa Ogundigie and Akihiro Ito *The Effects of Sodium Chloride, Miso or Ethanol on Development of Intestinal Metaplasia after X-Irradiation of the Rat Glandular Stomach,* Japanese Journal of Cancer Research, v 83, pp. 1267-1272, December 1992.

49. Wise, James A., Kristiina McConville, Nasr Al-Sahhaf *Managing Cultural Diversity in Orbital Habitats,* Engineering, Construction, and Operations in Space II: Proceedings of Space 90. Part II. Published by ASCE, Boston, MA, pp.1344-1353, 1990.