Agriculture for Space Exploration:
An Evolutionary Approach for Sustaining Space Agency Investments

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Plants in Space for Life Support

HUMANS

Metabolic Energy

food
(CH₂O) + O₂ → CO₂ + H₂O

Clean Water → Waste Water

Light

food
(CH₂O) + O₂⁺ + H₂O ← CO₂ + 2H₂O⁺

Clean Water ← Waste Water

PLANTS
Closed System CO$_2$ Uptake / O$_2$ Production
(20 m$^2$ Soybean Stand)

Photosynthesis in Space (1966)

Fig. 11. Experimental apparatus mounted in OVI satellite; note solar cell dome system.

Previous Testing on Large Systems with Staple Crops

Rice at CEEF Facility, Rokkasho, Japan
Wheat at Bios-3 Facility, Krasnoyarsk, Russia
Soybeans at NASA Kennedy Space Center, US

Start ➔ Vegetable Production Systems for ISS

Cosmonaut Gennady Padalka—Lada Chamber on ISS
Lada Chamber Ground Controls (0.025 m³)
BPSe or VEGGIE Chamber by Orbitec (0.13 m³)
WCSAR CPBF Chamber 0.25 m³ growing area
Early Missions--Supplemental Food Crops

- Provide fresh foods to supplement stowed foods
- Provide Bio-available nutrients and antioxidants as radiation countermeasure.

Expanded Food Production Systems for Transit / Near Earth Missions

"Phytoconveyor" (0.4 m²) Yuli Berkovich (IMBP)

"Salad Machine" (1.0-2.0 m²)
Mark Kliss and Bob McElroy (NASA)
Vegetable Production for "Transit Missions"

Deployable - Precursor Missions for Surface Settings

Placing Deployable Greenhouse in Vacuum Chamber (NASA KSC)  
(V. Rygalov, M. Dixon, J. Lawson)

Small Deployable Greenhouse at NASA Kennedy Space Center  
(R. Wheeler, P. Fowler, V. Rygalov)
Pre-Deployment Missions:
*Concept for Small Greenhouses or Plant Pods*

- Mars Night: Covers close at night for insulation
- Mars Day: Covers open in day and serve as reflectors

Surface Systems: Larger Plant Production Systems

- Inflatable Greenhouses for Crop Production

Attached Inflatable Greenhouses
Composting Facility

Human Habitat

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Solar Collectors for Crop Production

Buried Plant Growth Chambers (for radiation shielding)

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Surface Missions—Could Use Conventional Hydroponics

- Conserve Water & Nutrients
- Eliminate Water Stress
- Optimize Mineral Nutrition
- Facilitate Harvesting

Energy Efficient Lighting will be Needed such as LEDs

- Red...photosynthesis
- Blue...photomorphogenesis
- Green...human vision

John Sagar, KSC. Testing Prototype Flight Plant Chambers with LEDs
Solar Collector / Fiber Optics For Plant Lighting

Up to 400 W light delivered to chamber (40-50% of incident light)

2 m² of collectors on solar tracking drive (SLSL Bldg, KSC)

Light, Productivity, and Crop Area Requirements

Area Required (m²/person) vs. Productivity (g m⁻² day⁻¹) vs. Light (mol m⁻² day⁻¹)
Logistics Module → Surface Plant Module

- Logistics to Living Module
  - 3.5 meter diameter
  - 8.5 meter length
  - 3 segment module

- Logistics Bags
  - 167 logistics bags
  - About 7,064 kg logistics payload capacity

Open area at entrance required for hatch swing

Cut-Away View With Logistics Packaging

Logistics Module → Surface Plant Module

- Plant Trays
  - 72 plant trays
  - 0.23 m² each
  - 16.66 m² total
  - 36 trays, 48 x 48 cm with 40 cm clearance height
  - 36 trays, 48 x 48 cm with 60 cm clearance height

Port racks shown with some logistics bags at rear
Starboard racks not shown

Logistics to Living Module converted to a Plant Production Module
Thanks to my colleagues at NASA’s Kennedy Space Center