MOON BASE WORKSHOP

MOSCOW 16 – 17 November, 2006

INTEGRATION OF ANTARCTICA HYDROPONICS AS OPTION FOR FOOD PLANT LIFE SUPPORT IN SPACE

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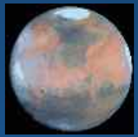
(Italian Agency for New Technologies, Energy and the Environment)

PNRA
Italian National Program
for Antarctic Research

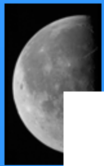


CLOSED HYDROPONICS FOR FRESH FOOD SUPPORT IN ANTARCTICA

at the Italian base MarioZucchelli BTN (Baia Terra Nova)

The advantages of PULSA can be summarised as follows:

- continuous **supplementing of fresh vegetables** by this artificial ecosystem allows to vary the diet of the base personnel, and brings a nutritional complement;
- availability of vegetable fresh food for **maintaining dietary habits** in extreme and isolated bases;
- operations on the artificial agro-ecosystem for production of plant biomass and fresh food are considered **positive activities for sustaining the wellbeing** of the scientific and technical staff;
- availability of PULSA a recreational and relaxing room as a way **to counteract the Seasonal Adjustive Disorder**.



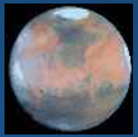
Importance of vegetable consumption on human diet

Crop	Human daily requirement	Lettuce (per 100 g)	% R.D.A.	Tomato (per 100 g)	% R.D.A.
Literature	www.benessere.com	http://www.nal.usda.gov/fnic/foodcomp/			
% Edible parts		**83**		**100**	
Water (g)	5400	**95**	1.8	**93.5**	1.7
Protein (g)	76	**1.36**	1.8	**0.6**	0.8
Total lipids (fats) (g)	101	**0.15**	0.1	**0.1**	0.1
Carbohydrate		**2.79**		**4.59**	
Fiber (g)	30	**1.3**	4.3	**0.8**	2.7
Kcal	2973	**15**	0.5	**22**	0.7
Sodium (mg)	1000	**28**	2.8	**6**	0.6
Potassium (mg)	3200	**194**	6.1	**193**	6.0
Iron (mg)	10	**0.9**	9.0	**0.42**	4.2
Calcium (mg)	800	**36**	4.5	**11**	1.4
Phophrous (mg)	800	**29**	3.6	**17**	2.1
Vit. B1 (mg)	1.45	**0.07**	4.8	**0.04**	2.8
Vit. B2 (mg)	2.18	**0.08**	3.7	**0.03**	1.4
Vit. PP (mg)	24.3	**0.375**	1.5	**0.73**	3.0
Vit. A (mg)	700	**194**	27.7	**610**	**87.1**
Vit. C (mg)	60	**40**	**66.7**	**27.7**	46.2

% R.D.A. = % of daily Recommended Dietary Allowances

Crop surface of PULSA for an Antarctica base of 20 people

CROP	LETTUCE	TOMATO
Plant density (n° plant m^{-2})	100	3
Cycle length (day)	22	90
Days to harvest	22	45
Harvest length	1	45
Total yield for cycle (kg m^2)	2.5	8
Daily yield (g m^2)	2.500	177.8
Daily portion (g man^{-1})	100	100
Number of persons	20	20
Total amount requested (g day^{-1})	2000	2000
Total surface required (m^2)	17.6	22.50



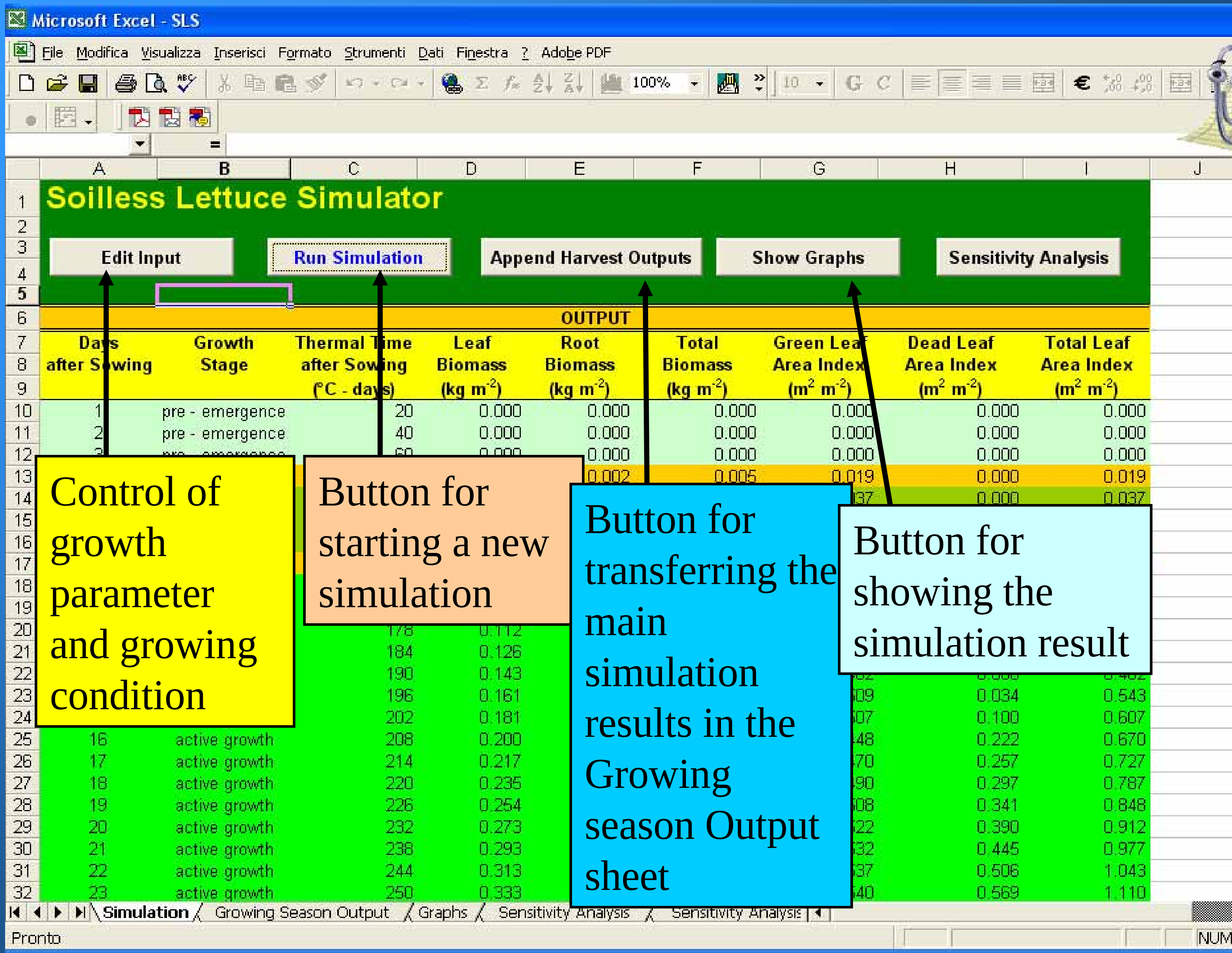
SLS: a tool for crop simulation in growth chamber

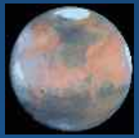
- **Soilless Lettuce Simulator is a product of a PNRA funded activity (2002-2003) on P.U.L.S.A. project.**
- **The SLS was developed by ENEA, DBPA-University of Pisa and ISCI Bologna.**

- A model for predict the total lettuce biomass growth in an artificial system (soilless system+ growth chamber) with the input of the average daily temperature and PAR levels.
- The main result is an excel-file that can predict the lettuce growth. This file can be downloaded from the web site: http://www.sipeaa.it/tools/SLS/SLS.htm .
- The work “Soilless indoor-grown lettuce (*Lactuca sativa* L.): approaching the modelling task” has been accepted for publication on “Environmental Modelling and Software”.

REFERENCE:

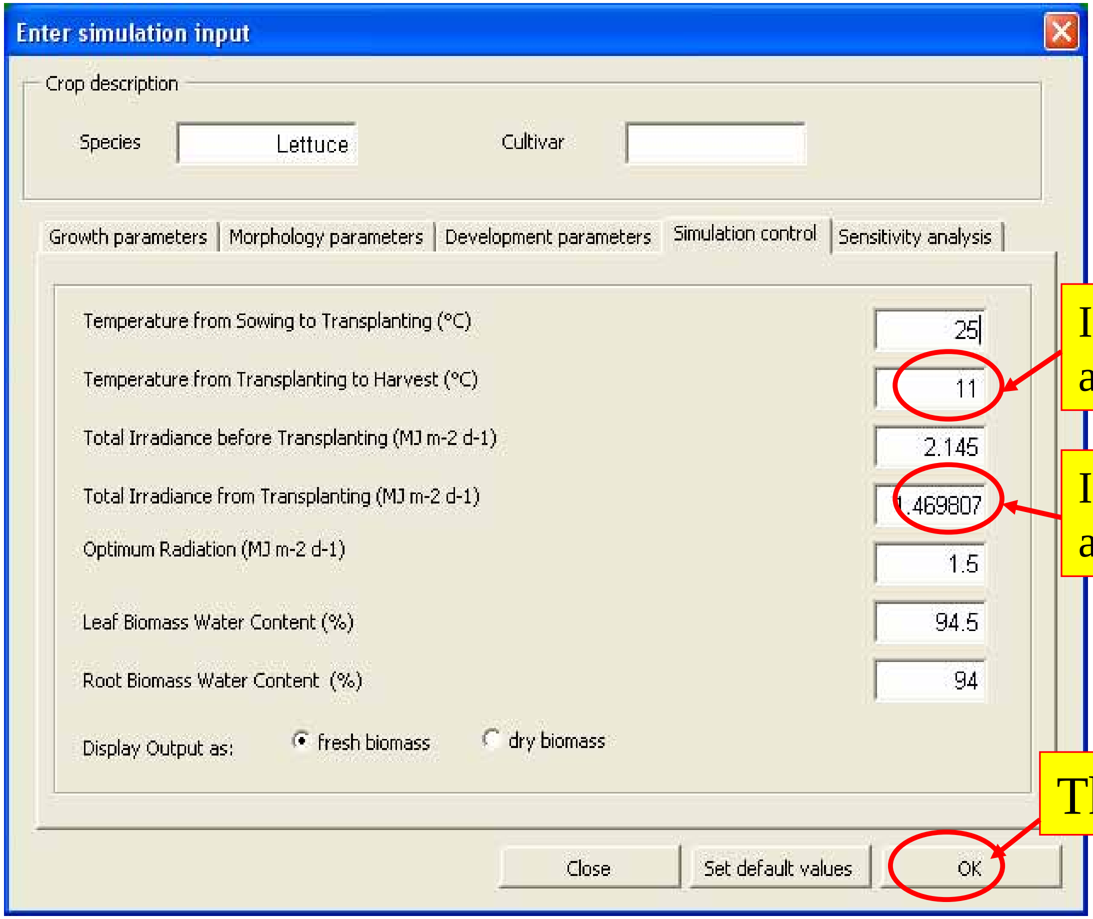
L. Incrocci, G. Fila, G. Bellocchi, A. Pardossi, C.A. Campiotti, R. Balducchi. Soil-less indoor-grown lettuce (Lactuca sativa L.): Approaching the modelling task. Environmental Modelling & Software (2005). (accepted for publication).


Microsoft Excel - SLS
File Modifica Visualizza Inserisci Formato Strumenti Dati Finestra ? Adobe PDF
Soilless Lettuce Simulator
Edit Input
Run Simulation
Append Harvest Outputs
Show Graphs
Sensitivity Analysis
OUTPUT
Days after Sowing
Growth Stage
Thermal Time after Sowing (°C - days)
Leaf Biomass (kg m-2)
Root Biomass (kg m-2)
Total Biomass (kg m-2)
Green Leaf Area Index (m2 m-2)
Dead Leaf Area Index (m2 m-2)
Total Leaf Area Index (m2 m-2)
pre - emergence
active growth
Control of growth parameter and growing condition
Button for starting a new simulation
Button for transferring the main simulation results in the Growing season Output sheet
Button for showing the simulation result
Simulation
Growing Season Output
Graphs
Sensitivity Analysis
Pronto
NUM



SLS: how to enter simulation parameter

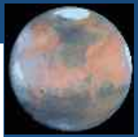
Click for open SLS



Insert the daily average temperature

Insert the daily average light

Then click on OK



SLS: a tool to optimize the energy costs of lettuce yield

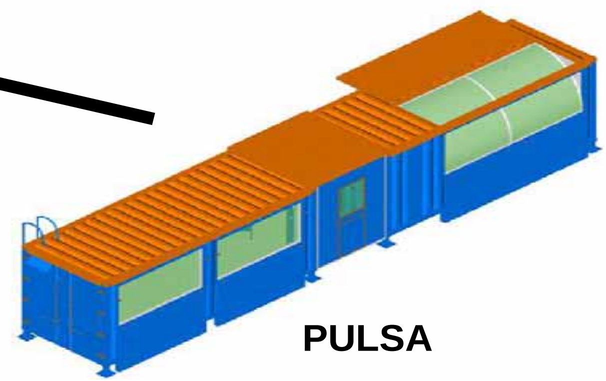
Is it better:
Low temperature-long cycle
or
high temperature-short cycle?

Temperature (°C)	Light ($MJ\ m^{-2}$)	Days from sowing to harvesting	Yield ($kg\ m^{-2}$)
12	1.0	37	0.4
12	2.5	37	2.1
20	1.0	22	1.8
20	2.5	22	2.7
35	1.0	22	1.7
35	2.5	22	2.7

Temperature
➢20 °C
is not
convenient.

HYDROPONICS LETTUCE BED

HYDROPONICS MULTICROPS



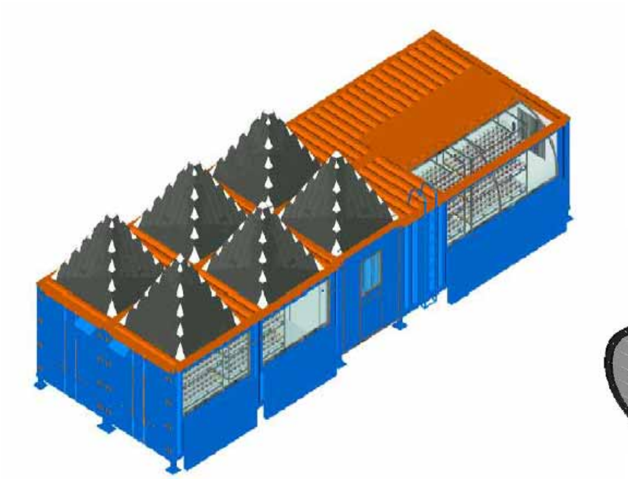
PULSA

(Terra Nova Bay, Antarctica

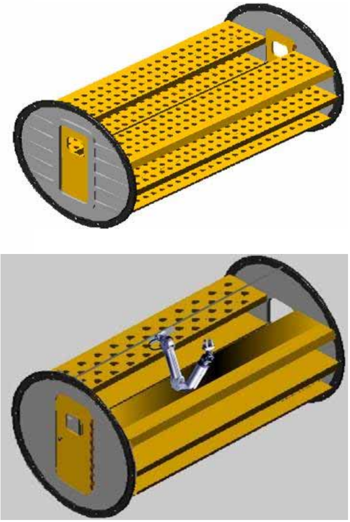
RESEARCH IN PROGRESS IN ANTARCTICA AND FOR SPACE

PV ENERGY – MULTILEVEL SYSTEM - LED LIGHTING

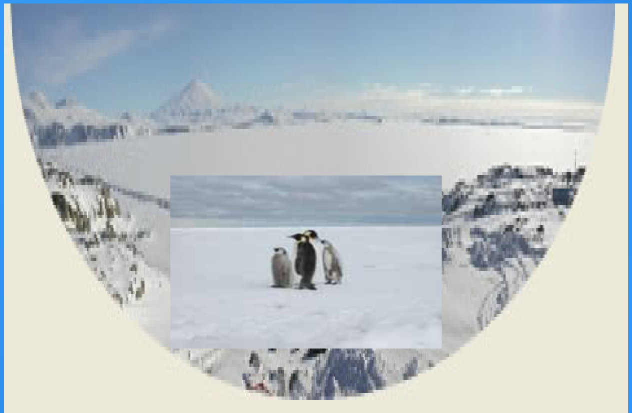
LED - LIGHTING



SOLAR CELL (PV)

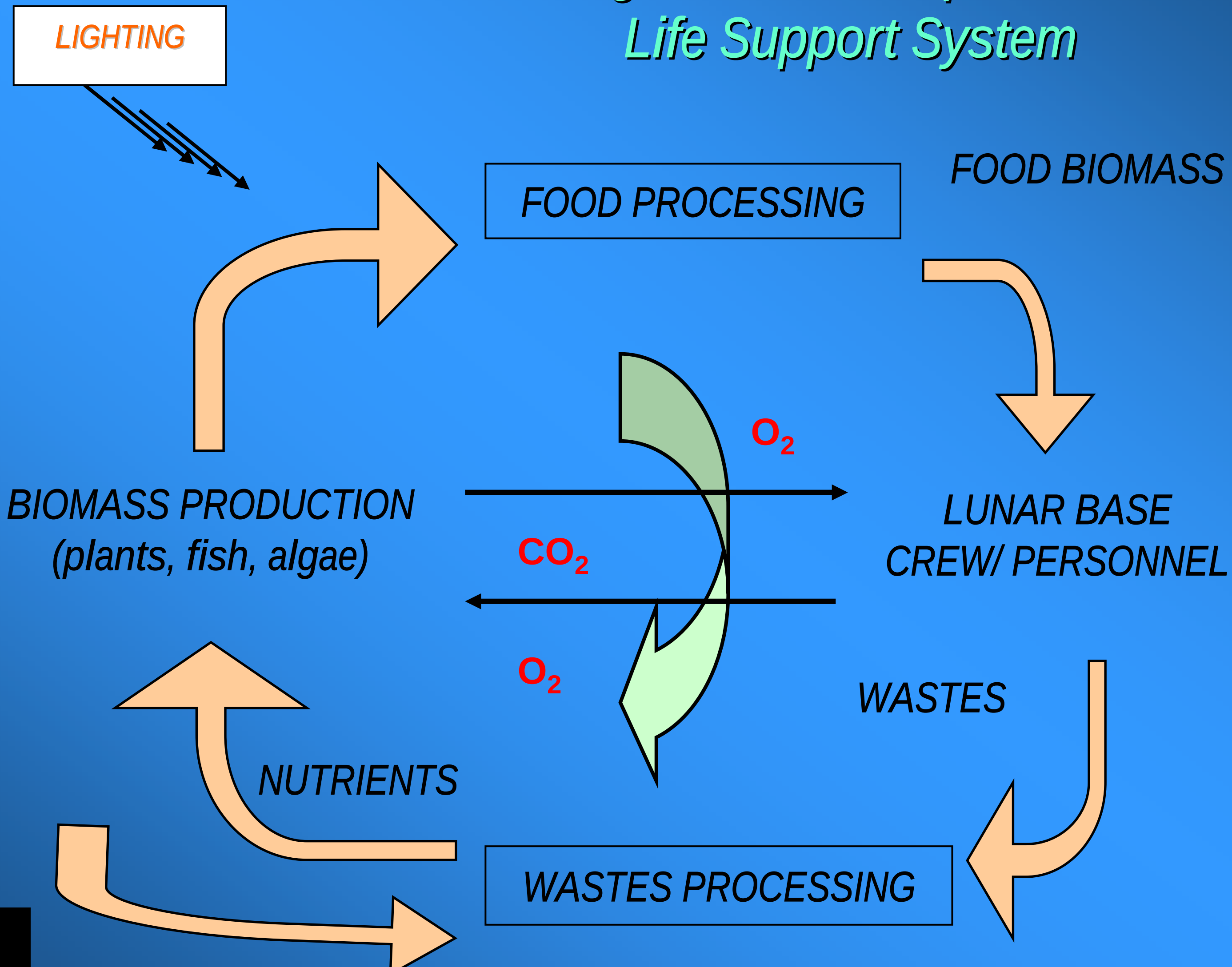


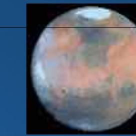
MULTILEVEL HYDROPONICS



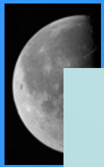
INTEGRATING ANTARCTICA EXPERIENCES FOR SPACE

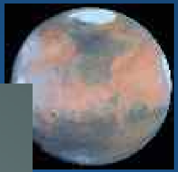
Biological Flow of a plant-based Life Support System





EARTH FOOD PLANT SYSTEMS (*Antarctica, Arctica, deserts...)*	SPACE FOOD PLANT SYSTEMS (*Lunar and Mars bases, missions…*)
Vegetable systems works at terrestrial gravity (9,81 ms^{-2}). Water and nutrients do not require specific technologies for feeding plants. Food plant is produced at atmospheric pressure of 70-100 kPa (101.3 kPa = 1 Bar = 750.1 mm of mercury).	Vegetable systems must work at microgravity of: 1,62 ms^{-2} (Moon) e 3.72 ms^{-2} (Mars). Water and nutrients require specific technologies for feeding plants because of micro-gravity. Food plant should be produced at low pressure of about 20 - 0.7 kPa. Moon pressure = 0 kPa ; Mars pressure = 1 kPa.
Productivity is scaled in weight per unit area (gm^{-2}).	Plant productivity should be scaled in weight per unit volume/per unit time/per unit energy input ($g\ m^{-3}$).
The *hydroponics terrestrial farm* can be automated or PC controlled.	The *hydroponics Space farm* MUST BE automated to optimize the plant food production efficiency.
The light for plants is integrated with WSDL lamps (wide-spectrum discharge lamps).	The light for plants will be integrated with WSDL lamps or semiconductor technology (LEDs-Light Emitting Diodes).
The plant by the photosynthesis contribute to provide food, oxygen and water. Solar flux = 1368 W/m^2. Length of day (hours) = 24.	The plants MUST PROVIDE food, oxygen and water. The food plant system MUST re-generate food and oxygen, and (purify) water, recycle wastes. Solar flux = 1368 W/m^2 (Moon) and 589 (Mars). Length of day (hours) = 708.7 (Moon) and 24.7 (Mars).





BIOAGRONOMIC CHARACTERISTICS FOR EXTRA-TERRESTRIAL PLANT SYSTEMS

1) Plants with high production to minimize the amount of space;

2) Crops with high nutritional and taste characteristics (carbohydrate, protein, fat, minerals &vitamins);

3) Simple propagation or self pollinating to simplify plant reproduction;

4) Plant phenotype with short stems (dwarf) and compact growth;

5) Crops with short growing life cycle;

6) Most of plant edible (high harvest index);

7) Food all digestible;

8) Many culinary uses (to allow a multiuse of the plant product);

9) Phenotype and plant cycle adapted of being automated.

PLANT FOOD RESOURCE IN THE WORLD	
N. of plant species	**Items**
250.000	**Plant species already known**
80.000	**Edible plants**
150	**Cultivated crops**
12	**Provide 90% of all the agro-food supply in the world**

PATHOGENS CONTROL AND FOOD SAFETY

As well known from terrestrial experience, hydroponics plant closed system need proper managing in order to avoid that potential contaminants (VOC's) in the gaseous atmosphere or pathogens (Pytium and Erwinia species) in the nutrient solution can create problems to plant growing process.

Also, the materials utilized in the space craft (tubing, valves, containers, plants) and the persons dealing with the fresh-food biomass need to be carefully checked for removing potential toxic contaminants and pathogenic micro-organisms.

Thus, daily monitoring and removal procedures need to be developed and applied to both plant process and people. This pose the question that a Space agriculture require the whole plant process to be essentially automated and run by robots.

MICROBIOLOGICAL QUALITY OF SOILLESS PLANTS

In hydroponics solutions and components are properly sterilized.

The system should be free from plant pathogens and human pathogens.

However:

- Spores of fungi and bacteria could be accidentally introduced.
- The use of re-cycled water or wastes could spread microorganisms.
- Microorganisms could colonize the rhizosphere and the plant organs.
- Biofilms could develop on the wet surfaces of the system.
- Plant pathogens and spoilage microorganisms could affect production and taste.
- Food-borne pathogens could spread on fresh vegetables.
- Opportunistic pathogens if present can affect immunologically depressed people.

Little is known about the ability of plant pathogens, food-borne pathogens and opportunistic pathogens to survive and colonize the plants and the system under the extreme growth conditions described.

The extreme growth condition could produce physiological plant disorders.

Evaluation of the microbiological quality of the hydroponics under different growth conditions

(Nutrient availability, O_2, Light, Temperature, Pressure)

1. Monitoring of the plant health in order to detect physiological disorders or disease syntoms.

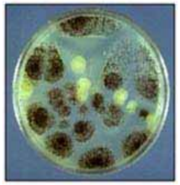
2. Monitoring of Bacterial and Fungal populations on the rhizosphere and plant organs
   Species Composition and fluctuation

3. Monitoring of biofilms on the wet surfaces
   Species Composition and Fluctuation

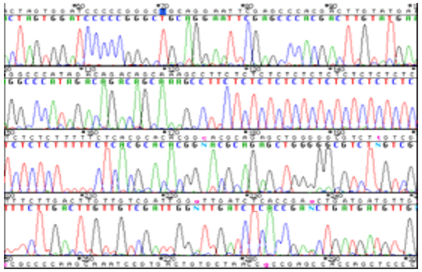
4. Detection of markers of food-borne pathogens on fresh food plants *(Coliforms, Enterobacteriaceae, Bacteroidetes, Staphylococcus aureus)*

Microbiological Methods

Cultural methods



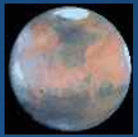
- Plate count of total Bacteria;
- Plate count of total Fungi and Yeasts;
- Isolation and plating on selective and differential media for identification;
- Community analysis by single carbon substrate metabolism (Biolog™ Plates).



Genomic Methods of identification

- DNA extraction, PCR amplification and sequencing of RNA ribosomal genes (16S rDNA for Bacteria, 26S rDNA for Fungi);
- comparison with GenBank Database (www.ncbi.nlm.nih.gov);
- Community study by 16S rDNA Amplicon Lenght Heterogeneity (ALH), using the DNA Automated Sequencer ABI Prism.

LIGHTING AND PLANTS IN SPACE

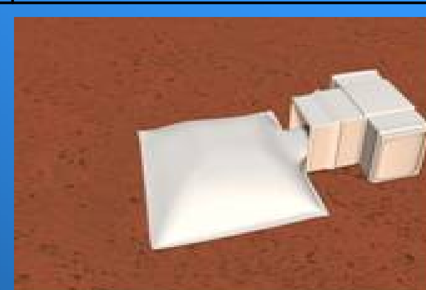


Lighting should not be considered as a separate growth factor when planning a greenhouse-space module. However, suboptimal levels of light (PAR) may cause problems to growing plant process and this results of particularly importance in Space stations or under orbital light conditions.

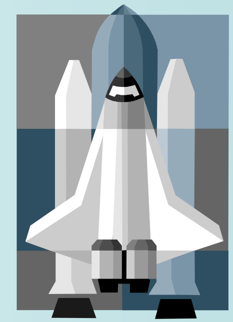
Geographical location	Photoperiod	Light condition
LEO (low earth cycles)	light:dark cycles are 60:30 minutes	Light supplementation
Moon	light:dark cycle is 14:14 days	Light supplementation
Earth	light:dark cycles are 12:12 hours	Light regulation
Antarctica	light:dark cycles are 6:6 months	Light regulation

DIFFERENT SPACE GREENHOUSE-MODULE

ENCLOSED (growth chamber)	INFLATABLE	MODULAR, INFLATABLE
Less plant space	More plant space	Multi crop combination
Higher plant cycle control	Good plant cycle control	Good plant cycle control
Less flexibility	More flexibility	Higher flexibility
Light/energy supply	Less light/energy supply	Less light/energy supply
Higher costs	Lower costs	Lower costs
More protection from radiation and dust	Less protection from radiation and dust	Less protection from radiation and dust
Plant pathogen risk	Plant pathogen risk	Lower pathogen risk
SUITABLE FOR SPACECRAFT	MOON/MARS BASES	MOON/MARS BASES



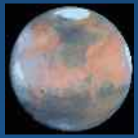
HUMAN BASE IN SPACE



HUMAN BASE IN ANTARCTICA

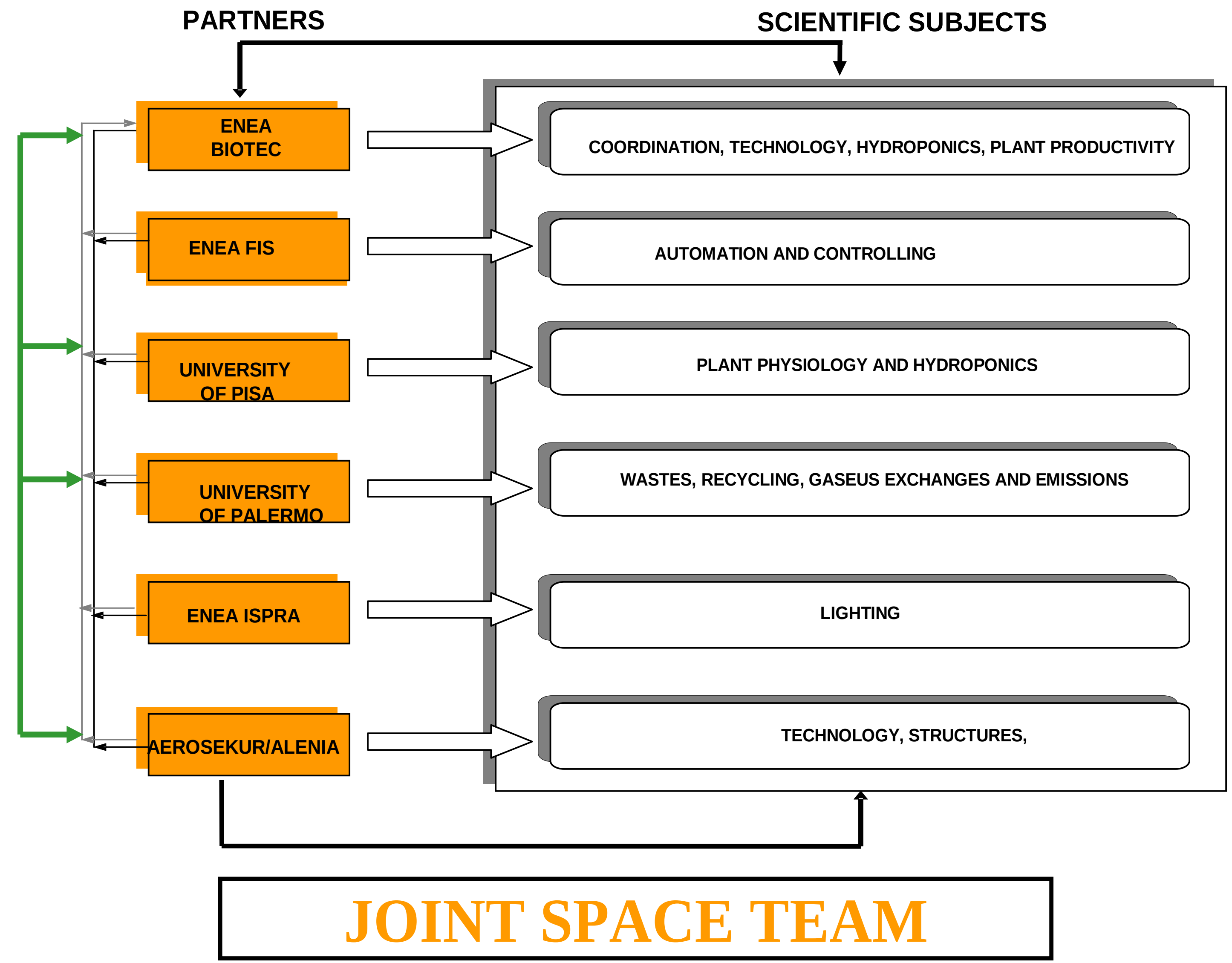
DOME-C

TASKS AND PROPOSALS 2006-2008



Over the next decades, the mankind will inevitably explore other planets and most probably will launch either a human mission to the Moon (2014?) or a human mission to Mars (2020?). For both missions plants will represent a key element since they can provide to humans food, oxygen and water and contribute to support long-term stays and eventually colonization of Space.

- ✓**How to deal with microgravity and low pressures when growing plants.**
- ✓**Assessment of selected plants crops and species for Space.**
- ✓**Defining of optimal plant process and growth conditions under Space environment.**
- ✓**Inflatable technology for Greenhouse-Space.**
- ✓**Cooperation between all actors (Academies, Research, Industries, Space agencies, etc.)**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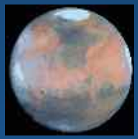
TECHNOLOGY, STRUCTURES,
JOINT SPACE TEAM

Thanks for attention



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