UNIVERSITY of GUELPH

Controlled Environment Systems Research Facility
Department of Environmental Biology
Guelph, Ontario CANADA
N1G 2W1 Tel. (519) 824-4120
Fax. (519) 837-0442

MELiSSA

Memorandum of Understanding

TOS-MCT/2002/3161/In/CL

Technical Note 76.3

Joint Progress Report to the Canadian Space Agency and the European Space Agency MELiSSA Program

For the Contract Period October 1, 2002 to December 31, 2002

Version 1

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Waters G., Dixon, M.A.

University of Guelph

Including a Higher Plant Chamber in the MELiSSA Loop

Joint Progress Report to the Canadian Space Agency and the European Space Agency MELiSSA Program

For Work Completed Under Canadian Space Agency Contract 9F007-010139/00/ST and European Space Agency MELiSSA Memorandum of Understanding TOS-MCT/2002/3161/In/CL dated January 2002.

For the Period of October 1, 2002 to December 31, 2002

Section 1.0 – Report Summary

Work on this project is progressing well. Studies with batch trials are, for the most part, complete. At some point in the future it may be necessary to replicate basic CO_2 response studies under batch planting. This need is dependent upon the results obtained from future light and CO_2 response studies for the integrated planting of beet and lettuce. At present, experiments are being conducted with integrated and staged planting of two of the three MEliSSA pilot plant crops (beet and lettuce; not including wheat). Gas dynamic models, including stand responses to light intensity are being developed for the integrated and staged stand. Early results will be obtained in the Winter of 2003 and reported in the Spring of 2003.

Section 2.0 : Report on Tasks

Task 1.1 – Development of Dynamic Carbon Exchange Models for Monocultures
Status - Complete

A series of experiments with monocultures, both in batch and staged planting have been completed using beet and lettuce. These studies have been reported upon in the interim report from the period July 2002 – October 2002.

Task 1.2 – Assess Degradation Efficiency of Inedible Biomass in Compartment I
Status – In Progress

We are continuing to work in collaboration with EPAS to derive estimates of degradation efficiency in Compartment I of the MELiSSA loop. We are in the process of arranging to ship dried plant material collected from our chamber studies at the University of Guelph to the EPAS laboratories in Belgium. The receipt of these materials will allow EPAS to conduct degradation studies using plant material produced under defined environment conditions.

Task 1.3 Development of Carbon Exchange Models for the Integrated Canopy
Status – In Progress

1.3.1 **Study Objective**

The purpose of this series of studies is to evaluate the effect of multiple crops with rotational planting on the net carbon exchange rate (NCER), evapotranspiration, and nutrient uptake dynamics within a sealed environment. Two of the three MELiSSA candidate crops, beet and lettuce, were continuously grown with a ten day staggered planting interval. This resulted in a plant canopy with all representative stages of physiological growth within a common atmosphere. At the present time the first replication in a series of studies has been completed as outlined below. Data resulting from the study are presently being analyzed to develop the carbon exchange models fro the integrated canopy. In general, the experiment performed well with only minimal indication of plant stress in the integrated planting environment. Following the results of this study more experiments will be conducted in a similar manner to validate carbon exchange models developed from empirical data collected in this study.

The objectives of this study were as follows:

1.3.1.1. Monitor CO_2 and O_2 gas exchanges
1.3.1.2. Monitor evapotranspiration
1.3.1.3. Monitor nutrient uptake
1.3.1.4. Evaluate various harvest parameters
1.3.1.5. Implement concurrent integrated canopy light curve experiments
1.3.1.6. Develop an empirical model of carbon exchange for the integrated canopy
1.3.1.7. Develop associated models for evapotranspiration and nutrient uptake

1.3.2 Study Test Parameters

CO_2, O_2 and evapotranspiration were recorded at 3 minute intervals by the Lander control system. Crop wet and dry weights of edible and inedible biomass and other growth parameters (specific leaf area, leaf area, root:shoot ratios) were determined at each harvest interval. Nutrient uptake analysis by HPLC was performed at the beginning and end of each nutrient solution cycle.

1.3.3 Study Period

The study period refers to the time between initiation and completion of analysis.

Starting Date:	September 30, 2002
Completion Date:	January 8, 2003

1.4.4 Study Site

The study was carried out at: Controlled Environment Systems
SEC2
University of Guelph
Guelph, Ontario

1.5.5. Study Procedures

Planting: Seeds (lettuce - cv. Grand Rapids [185C] 45 days; and beets - cv. Detroit Dark Red Medium Top [34] 63 days; both from Stokes Seeds) were sown directly into individual pre-rinsed (de-ionized water) rockwool blocks (12 blocks of beets and 12 blocks of lettuce per chamber per planting interval). The depression in each block was half filled with sand, followed by three seeds and additional sand. After sowing, the doors were sealed and the experiment began. At each harvest/planting interval, the 10-day-old plants were thinned to 1 plant per block. Planting was performed as per the attached planting/havesting schedule.

Watering: Plants were watered using a recirculating NFT irrigation system consisting of a 160 L in-chamber reservoir and 10 stainless steel growing trays. Nutrient solution (see Table 1) was changed every five days.

Harvesting. Lettuce and beets was harvested according to the planting and harvesting schedule (attached). Lettuce was harvested 40 days after planting, and beets 60 days after planting.

1.3Lof nutrient stock solution was added to 160 L of de-ionized water to make the nutrient solution. Also 3.5 g of $FeCl_3$ was added at this time.

Detailed procedures which were carried out from time to time were recorded in the SEC2 experiment log book.

1.3.6. Sampling Schedule

The majority of sampling of the atmospheric phase was done automatically. Sampling of the hydroponics solution was performed at the beginning and end of each nutrient cycle (5 days).

1.3.7 Analytical Methods

Nutrient solution composition was analyzed according to SOP CES-02-007.

1.3.8 Data Analysis and Delivery

Data are presently being prepared for analysis. Results of preliminary or final analysis will be made available following the next contract period.

Task 1.4 Development of Dynamic and Steady State Models for the HPC
Status – In Progress

1.4.1 Study Objectives

The purpose of this series of studies is to employ data collected in empirical data (collected by the University of Guelph, within the European Space Agency (ESA) – MELiSSA consortium and as presented by other researchers in the area of Bioregenerative Life Support to develop dynamic and steady state models for the higher plant chamber. Meetings within the ESA-MELiSSA consortium have identified wheat, beet and lettuce as initial candidate crops for integration in the pilot plant. As such, models to be developed will include these crops as component of the HPC. Specifically the objectives of this study are:

- 1.4.1.1 –Formulate a conceptual model for carbon nutrient and water dynamics using the higher and lower level mapping layer of the STELLA dynamic modeling software
- 1.4.1.2 –Evaluate the possibility of translating dynamic models of the HPC directly to Simulink and/or Matlab
- 1.4.1.3 –Incorporate empirical data collected in relevant studies to develop a model of mass dynamics under various lighting intensities, planting densities, atmosphere-biomass ratios for an integrated crop
- 1.4.1.4 –Evaluate the performance of the Modified Energy Cascade Model (MEC) as presented in the NASA document relative to dynamic models developed using empirical data under the same modeling scenarios described above
- 1.4.1.5 –Decide upon a suitable working model for the HPC as a component of the MEliSSA loop and full system modeling studies

1.4.2 – Comparison of Mechanistic (MEC) and Empirical Models of the HPC

The top-level MEC model as proposed by Cavazzoni (2001), Volk *et al*., (1995) and Monje and Bugbee (1998) makes use of a number of variables and is mechanistic in nature. We have determined that this model is a *potentially* suitable mechanistic approach to describing carbon dynamics in the HPC. The model, which is described in detail by Hanford (2002), is partially reproduced here for the benefit of the reader. Empirical data collected from the studies described in Task 1.3 will also be used to develop a model of mass dynamics and compared to that of the MEC. This involves the generation of two separate models – one based on empirical data and the other based on the mechanistic MEC approach.

1.4.3 – Performance Evaluation of Models

The mechanistic MEC model will be the first to be implemented in the STELLA environment. Following the development of mass dynamic models as outlined in Task 1.3, the MEC model is deemed accurate in the integrated production case if the dynamic and steady state results of the model predict the NCER and nutrient dynamic results from the empirical studies at static and variable light intensities. At this time however no inclusion of nutrient dynamics within the MEC framework has been provided (Hanford, 2002). It is an additional objective of this work to further develop the MEC approach to include nutrient dynamic.

1.4.4 – Details of the MEC Modeling approach

1.4.4.1 – Canopy Light Interception

The fraction of PPF absorbed b the plant canopy, A, is a function of time, t, in terms of days after emergence [d_{AE}] and the time for canopy closure, t_A [d_{AE}]. It is given by the following relationship:

$$A = A_{Max}\left(\frac{t}{t_A}\right)^n \qquad \text{for } t < t_A \qquad \text{[Equation 1.4.4.1.1]}$$

$$A = A_{Max} \qquad \text{for } t \$ t_A \qquad \text{[Equation 1.4.4.1.2]}$$

where the values of the exponent, n, may range from 1.0 to 3.0.

1.4.4.2 – Canopy Quantum Yield

The canopy quantum yield, CQY, [µmol $_{\text{Carbon Fixed}}$ / µmol $_{\text{Absorbed PPF}}$] is given by:

$$CQY = CQY_{Max} \qquad \text{for } t \# t_Q \qquad \text{[Equation 1.4.4.2.1]}$$

$$CQY = CQY_{Max} - (CQY_{Max} - CQY_{Min}) \cdot \frac{(t - t_Q)}{(t_M - t_Q)} \qquad \text{for } t_Q < t \# t_M \qquad \text{[Equation 1.4.4.2.2]}$$

where t_M is the time at crop harvest and t_Q is the time at onset of canopy senescence.

1.4.4.3 – Carbon Use Efficiency, Oxygen Production and Daily Carbon Gain

The 24 hour carbon use efficiency, CUE_{24}, a fraction, is constant for most crops, and such a single value is used for the three crops (wheat, lettuce and beet) used in this study.

The daily carbon gain, DCG, [mol_{Carbon}/m^2Ad] is computed from:

$$DCG = 0.0036 \frac{s}{h} \frac{mol}{mmol} \cdot H \cdot CUE_{24} \cdot A \cdot CQY \cdot PPF \qquad \text{[Equation 1.4.4.3.1]}$$

where H is the photoperiod [h/d] for a given crop.

In turn, the daily oxygen production, DOP, [mol_{O2} / m^2Ad] may be computed using:

$$DOP = OPF \cdot DCG \qquad \text{[Equation 1.4.4.3.2]}$$

where OPF is the oxygen production fraction [mol $_{O2}$ / mol $_{Carbon}$].

The crop growth rate, CGR [g/m^2 Ad], is related to DCG by:

$$CGR = MW_C \cdot \frac{DCG}{BCF} \qquad \text{[Equation 1.4.4.3.3]}$$

where MW_C is the molecular weight of Carbon, and BCF is the biomass carbon fraction.

Total crop biomass, TCB [g/m_2] can in turn be calculated from the integral of the DCG over the period of interest and the total edible biomass estimated from the fraction of daily carbon gain allocated to edible biomass. Also, polynomial functions are required to describe $CQY_{Max.}$

Variable	Units	Description
A	--	fraction of PPF absorbed by the plant canopy
A_{max}	--	maximum value of A
BCF	--	biomass carbon fraction
CGR	g/m2⋅d	crop growth rate
C_i	varies	coefficients in functions describing t_A and CQY_{max}
$[CO_2]$	µmol CO_2 / mol $_{Air}$	atmospheric concentration of carbon dioxide
CQY	µmol $CO_{2\ fixed}$ / µmol $_{Ab.PPF}$	canopy quantum yield
CQY_{max}	µmol $CO_{2\ fixed}$ / µmol $_{Ab.PPF}$	maximum value for CQY that applies until t_Q
CQY_{min}	µmol $CO_{2\ fixed}$ / µmol $_{Ab.PPF}$	minimum value of CQY at t_M
CUE_{24}	--	24-hour carbon use efficiency
CUE_{max}	--	maximum value for CUE_{24} that applies until t_Q
CUE_{min}	--	minimum value of CUE_{24} at t_M
DCG	$mol_{Carbon}/m^2 \cdot d$	daily carbon gain
DOP	$mol_{Oxygen}/m^2 \cdot d$	daily oxygen production
H	h/d	photoperiod
MW_c	g/mol	molecular weight of carbon
n	--	an exponent
OPF	mol O_2/mol CO_2	oxygen production fraction
PPF	µmol $_{photon}$ / $m^2 \cdot s$	photosynthetic photon flux
TCB	g/m^2	total crop biomass
TEB	g/m^2	total edible biomass
t	d_{AE}	time
t_A	d_{AE}	time until canopy closure
t_E	d_{AE}	time at onset of organ formation
t_M	d_{AE}	time at harvest or crop maturity
t_Q	d_{AE}	time until onset of canopy senescence
XFRT	--	fraction of daily carbon gain allocated to edible biomass after t_E

Table 1.4.4.1 – Summary of Modified Energy Cascade Model (MEC) Variables for Biomass Production (after Hanford, 2002)

1.4.5 – Status of the Modeling Effort

This task is currently underway and the translation of the MEC model into the STELLA environment has begun. Concurrently, data collected from the experiments described in Task 1.3 are presently being analyzed to be used in both empirical model development and in the validation of mechanistic model (MEC). Preliminary results of these modeling studies will be made available at the end of the next reporting period.

Task 2.1 – Assessment of System Level Mass Balance with Respect to Water, Nutrients, Gases and Biomass

This task is underway using information gathered from Tasks 1.1 – 1.4. Some additional work with wheat in batch and staged planting will need to be completed before a complete assessment of system level mass balance can be performed.

Tasks 3.1 – 5.1

The bulk of these tasks are underway but are not yet due to be reported upon. Note that task 4.1 is a direct MELiSSA partner objective

To be Completed in Next Reporting Period

Task 1.2 – Report on efforts related to degradation efficiency trials with beet and lettuce material sent to the EPAS laboratories in Belgium

Task 1.3 – Report on the results of data analysis and empirical modeling results relating to carbon exchange dynamics in the integrated canopy of beet and lettuce (first set of the experiments are complete – data analysis to follow)

Task 1.4 – Report and the use of MEC models in the STELLA environment and its utility in modeling carbon, water and nutrient dynamics in integrated crop production

Appendix 1 – Summary of Milestones

1. **Steady State and Dynamic Modeling of the Higher Plant Chamber (HPC)** – The purpose of this objective is to collect data relevant to the dynamic and static modeling of the HPC, including harvest yield and partitioning, crop response (NCER, transpiration, nutrient uptake) to environment conditions (light and CO_2) and the degradation of inedible biomass in the fermentative compartment. The development of empirical models from the resulting data set will then be used to assess steady state of the loop including the HPC. (UoG, CF, EPAS)

2. **Integration of Steady State Models for All MELiSSA Compartments including the HPC** – This objective aims at assessing steady state of the MELiSSA loop including the HPC, with respect to CO_2, O_2, water, major nutrients (including those materials from the degradation of inedible biomass in the fermentative compartment). (CF, UoG)

3. **Sizing of the HPC and the Development of Cultural and Atmospheric Management Strategies** – From the data collected for various crops, particularly with respect to crop NCER responses to environment variables, management strategies for the stabilization of long and short term gas and water exchange dynamics will be established. Cultural management strategies for the production of candidate crops in a common atmosphere will also be established based on the same data (UoG, CF)**.**

4. **Development of Control Algorithms of the HPC –** The Higher Plant Compartment has to be elaborated and tested on a simulator before being transferred into the controller of the pilot process, as it has been done in the current MELISSA project for other compartments (ADERSA, Guelph)

5. **Design of the HPC Compartment and Interface with Other Compartments –** An HPC will be designed based on the results of the steady state and dynamic simulations, with particular emphasis on its interface of other compartments (UAB, EPAS, ADERSA, CF, UoG)

Appendix 2 – Summary of Schedule and Milestones

Deliverable	Forecasted Completion
0.0 Kick-Off meeting, appointment of PDF	Nov., 2001
1.1 Development of dynamic carbon exchange models for monocultures 1.2 Assess degradation efficiency of inedible biomass in compartment I* 1.3 Development of carbon exchange models for the integrated canopy 1.4 Development of dynamic and steady state models for the HPC	Mar., 2002 Dec., 2002 Mar., 2003 Oct., 2003
2.1 Assessment of system level mass balance with respect to water, nutrients, gases and biomass	Jan., 2004
3.1 Development of models for atmospheric management of integrated canopies under staggered planting and photoperiod offset 3.2 Validation of models of mass dynamic for integrated canopies under staggered planting and photoperiod offset 3.3 Determination of the HPC size required for interfacing with the MELiSSA loop	Mar., 2004 Jun., 2004 Oct., 2004
4.1 Software of the simulated process written with Simulink® and Matlab® advanced languages 4.2 Model Based Predictive Control software written in C language 4.3 Specifications of the sensors and actuators 4.4 Implementation of the control in a PC by means of a DLL (Dynamic Link Library) directly built from the C language software, without any transcription of the C software into another automated language	Oct., 2002 Jun., 2003 Oct., 2003 May, 2004
5.1 Design of the Higher Plant Chamber for loop integration based on results of previous studies	Dec., 2004
Annual Report and Annual Review Annual Report and Annual Review Annual Report and Annual Review Final Report	April, 2002 April, 2003 April, 2004 Mar. 31, 2005

* Indicates a Milestone that is behind schedule

Appendix 3 – Project Management Timeline

Public Works and Government Service Canada	**Contract Plan and Report Form**
Contract No. 9F007-010139/00/ST, **Requisition No.** 9F007-010139, **File No.** 009ST.9F007-010139 **Contractor:** University of Guelph, Controlled Environment Systems Research Facility	

Task Description		**Task Duration**													
	11/01 – 03/02		04/02 – 09/02		10/02 – 03/03		04/03 – 09/03		10/03 – 03/04		04/04 – 9/04		10/04 – 03/05		
1.1 [Note 1]															
1.2 (with EPAS)															
1.3															
1.4															
2.1 (with Clermont)															
3.1															
3.2															
3.3															
4.1 (with ADERSA)															
4.2 (with ADERSA)															
4.3 (with ADERSA)															
4.4 (with ADERSA)															
5.1 (with UAB)															
Annual Report & Review															
Annual Report & Review															
Annual Report & Review															
Final Report															
Original Estimate		Note 1. Task 1.1 is reported upon in ESA TNs 50.1 and 50.2. Since these TNs are also the subject of the first annual report under this contract, the first of the joint reports filed to ESA is the period covering April 1 – June 30, 2002. An addendum to the original TNs 50.1 and 50.1 is currently under preparation for the reasons noted in the progress and reporting section for Milestone 1.1													
Completed															
In Progress															

For more information relating to the technical or scientific aspects of this work, please contact:

Dr. Geoffrey Waters
NSERC Post-Doctoral Fellow
CESRF, Department of Environmental Biology
University of Guelph
E.C. Bovey Building
N1G 2W1
e-mail: waters@ces.uoguelph.ca