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LADA: THE ISS PLANT SUBSTRATE MICROGRAVITY TESTBED

Gail E Bingham, T. Shane Topham and John M. Mulholland

Space Dynamics Laboratory, Logan, Utah 84341

I.G. Podolsky

Institute of BioMedical Problems, Moscow, Russia

ABSTRACT

Lada, named for the ancient Russian Goddess of Spring, is a plant growth system developed jointly by the Space Dynamics Laboratory and the Institute of Biomedical Problems for long-term deployment on the International Space Station. Lada uses design features and technology similar to the Svet greenhouse on the Mir orbital outpost, and will be launched to ISS in June 02. It is scheduled to support its first crop (a leafy vegetable – Mizuna [Brassica rapa var. nipposinica]) in October 02. Lada consists of four major components (a control module, two vegetation modules and a water tank) and is designed to be deployed on a cabin wall. This deployment scheme was chosen to provide the crew therapeutic viewing and easy access to the plants. The two independently controlled vegetation modules allow comparisons between two vegetation or substrate treatments. The vegetation modules consist of three sub-modules, a light bank, the leaf chamber, and a root module. The root module is 9 cm deep, and can be instrumented to allow a wide range of substrate water and oxygen diffusion experiments to be conducted during the plant growth experiments. Sensors available in Lada are similar to those provided by the Svet-GEMS system. Specific attention has been paid to the root zone sensor suite, which includes substrate moisture probes, mini-tensiometers, and substrate oxygen sensors.

Experiments conducted in Lada will be associated with the Russian National Science program and will follow three themes: substrate management physics, plant production and quality, and crew – plant interaction studies. A unique feature of the Lada concept is that when the system is not being used for supported science experiments, it will be available to crew members to supplement their diet and to enhance flight enjoyment. Plans are in place to train all of the Russian crew members to use Lada. International cooperative experiments exploiting these unique features are now being developed.

INTRODUCTION

A new greenhouse of the *Svet* style is being prepared for deployment in the Russian section of the International Space Station (ISS). *Svet* was used for seven experiments on Mir between 1990 and 2000. In these seven formal experiments, 12 crops were grown from seed to harvest, resulting in the most successful Microgravity (μg) plant experiment sequence ever completed. These international experiments laid the groundwork for many of the new plant growth activities that are being planned for the ISS, and provided several keynote discoveries and demonstrations in the last decade. These include: the development of a reliable substrate moisture control system (Ivanova and Dandolov, 1992; Bingham et al, 1996; Bingham et al., 1999; Jones and Or, 1999), the identification ethylene as the limiting factor in earlier seed to seed failures (Salisbury, 1997; Campbell et al, 2001) and the identification of the likely ethylene source (Bingham et al, 2000). This experiment sequence also included the first replicated seed to seed experiment (Brassica rapa L. Musgrave et al., 2000), and the first two-generation microgravity seed production experiment (Sytchev et al., 1999; Bingham et al, 2000). The Svet-GEMS system also hosted the first salad crop experiments conducted in μg (Ivanova et al, 1992; Levinskikh et al, 2001), culminating in a cosmonaut taste test of salad greens aimed at future efforts to supplement the flight diet.

Lada was developed under a joint cooperative agreement between the Institute of Bio-Medical Problems (RAS, Moscow, Russia) and Space Dynamics Laboratory / Utah State University. Lada has completed qualification and biotechnology testing and is expected to launch to the ISS in mid 2002. Lada was developed to allow the Russian National Program on Microgravity Plant Technology to continue into the ISS era. Cooperation with other International partners is being sought for experiments utilizing Lada.

DESIGN CONSIDERATIONS

The Lada design follows the basic principles of the Svet-GEMS system, in that it is a wall mounted system optimized to provide long term, ready access for cosmonaut interaction. Like Svet, it provides light and root zone control, but relies on the cabin environmental control systems for humidity, gas composition, and temperature control. That is, cabin air is pulled into the leaf chamber, flows over the plants and vents through the light bank to provide both gas exchange and light bank ventilation. Wall mounting in the crew cabin with sliding door access to the plants, allows ready access to plants by cosmonauts, providing a kind "walk in the garden" psychological boost for the crew.

Unlike Svet, Lada uses two separate leaf chambers to allow treatment comparisons. The total plant growing area is one half that of Svet, but is divided into separate Vegetation Modules so that the treatments do not interact. The Svet root module was divided into two zones, allowing substrate conditions to be varied, but the plant vegetation area shared the same leaf chamber and lighting system. A more vigorously growing treatment in one root area could expand and shade the comparison crop. With Lada, the root module, leaf chamber and light bank for the two systems are completely separate. Lada utilizes the same type of lighting and substrate moisture control technology and approaches that were present in Svet, but with lower volume and power requirements. Commercial, off the shelf components are used extensively in Lada.

While Lada provides extensive leaf chamber light and temperature measurements, the most significant diagnostic effort is centered on the root zone. Lada root modules have the same plant growth area as the BMPS, but the depth is 9 cm to allow full root development for long experiments. Sensors for moisture, matric potential and substrate oxygen concentration can be mounted at various levels to measure profiles in the root zone.

LADA COMPONENTS

Lada was designed to provide the same good plant growth conditions and measurement capability that were provided by the Svet – GEMS system, except photosynthesis and transpiration. This section provides additional description of the individual modules.

Figure 1: The Lada Greenhouse was developed by SDL and IBMP for the Zvezda module of the ISS.

CONTROL AND DISPLAY MODULE

This module contains the power converters, the data acquisition and control system and the display and data storage unit. The system provides manual and automatic control of all Lada functions, including substrate moisture, light period, photography, measurement period and data and command communications. It also provides power and data interfaces for future modules such as animal or aquatic habitats.

The Lada Control Module is shown in the upper center of Figure 1. The upper portion of the control module is a display and interface unit, which provides long term program and data storage and data display functions. It also has connectors to support external hardware such as a 3.5 FDD, PS/2 mouse, and parallel printer. The upper section also has an RS232 serial connection that is wired in parallel to the lower section. This connection allows control module operations to be conducted from a separate laptop computer, should the display terminal fail. The display terminal also has a DC 16V-in connection for operation when 28 VDC power is not available, a USB port, an infrared port, and a PCMCIA slot.

The display terminal is a modified Casio Cassiopeia FIVA model MPC-101M62E display terminal and is used in conjunction with the Lada Software System (LSS) to provide a user-friendly interface to Lada. The user has access to the control module and can visualize data through the display terminal. Data on the display terminal hard disk can be backed up on an IBM 340MB microdrive. The microdrive is inserted into the PCMCIA slot of the display terminal . A separate microdrive contains a compacted version of the display terminal operating system as well as an LSS installation program. If data on the display terminal internal hard drive is lost or if the hard drive is not functioning properly the display terminal can be run from programs on the microdrive, or can be used to re-establish the software on the terminal hard disk.

The lower section of the CM houses a CR10X microcontroller and data logger, the DC/DC power converters, and various other circuit boards. All voltage measurements from the growth module and instructions from the display terminal for the growth module are processed in the lower section.

The switches and LEDs on the front of the CM control and display the status of the Lada power conversion and distribution system, including the availability of 28V power from the ISS. Between the upper and lower sections of the CM are four connectors: a USB port, 9-pin RS232 serial port (display terminal to CR10X), 4-pin power connector (2 pins for 16V power supply to the display terminal, 2 pins for the CR10X back-up battery), and a 2-pin O_2 sensor connector.

A power supply board, the CR10X, and two AM25T input multiplexer boards are connected to the 4 64-pin connectors of the main control board. Two communication connectors are located on the bottom of the CM. These connect to the growth modules via standard SCSI cables.

The CR10X in conjunction with LSS provides automatic control of greenhouse actuators and saving of plant growth data. The CR10X can be set to record data to memory every 20 minutes or every hour. The CM houses a cabin air temperature sensor, cabin absolute pressure sensor, cabin relative humidity sensor, cabin air oxygen concentration sensor, and a cabin air carbon dioxide concentration sensor. The cabin air temperature sensor incorporates a copper constantan thermocouple. The control module includes a cabin oxygen partial pressure sensor which is designed for easy replacement (every two years).

GROWTH MODULE

The LADA Growth Modules (GM) are the two outside components in Figure 1. The Growth Module supports the plants, and consists of three sub-modules, the Root Module (RM), the Leaf Chamber (LC) and the Light Module (LM). Each GM provides a 14 x 18 cm (252 cm^2) plant growth area.

Root Module

The root module consists of three sections, a sensor connection tray (bottom), a water distribution assembly (right), and the substrate and sensor container. The root module is made of black Delrin and is designed to provide ideal substrate conditions for plant growth. The control panel of the RM sensor sensor connection tray (see Figure 2) provides control switches for the primary (PUMP 1) and backup (PUMP 2) water pumps. Each 3-position locking switch is housed with a green led. In AUTO (left) position the LED lights up indicating the CR10X has control of the respective pump. In “OFF” and “ON” position the pump is manually turned off or on, respectively.

Figure 2: The Root Module has the three sections, the substrate container, the sensor interface tray on the bottom (with pump controls), and the water distribution section (which contains the pumps).

On the lower right side of the RM is a 9-pin communication connector for connection with the pumps, and a switch for selecting for which pump the CR10X will monitor. A 40-pin connector is located on the lower left side of the RM to provide communications and power from the CM, via the Light Module.

The substrate- and sensor-containing portion of the RM (see Figure 3) is made of black Delrin and has 20 threaded sensor holes in the bottom for various sensors placement per experiment specifications. Plugs are placed in the remaining unused holes. In the initial operations, the RM is filled with a porous (*Turface*1-2 mm) substrate. *Osmocote* time release fertilizer is used with the substrate. On the inside of the RM running lengthwise are 4 porous SS water tubes connected to the water distribution assembly using PUMP 1. The pumps are small commercial peristaltic units, powered by a switched DC circuit. The Lada RM uses the coated fabric wick material which was used in the Svet RM, The wick is folded around the porous tubes to support the seeds.

The RM are configured to support up to 16 sensors, including four O_2 concentration sensors, six soil moisture probes (which also function as temperature sensors), two wick moisture probes, and four micro tensiometers. The levels of all of the sensor types can be adjusted when the root module is packaged, depending on experiment requirements. The flexible wick moisture probes are placed lengthwise inside the wicks. The wick moisture probes and soil moisture probes are a thermal pulse type similar to those used in Svet. The mirco tensiometers are primed when the substrate is wet in flight, using the backup pump.

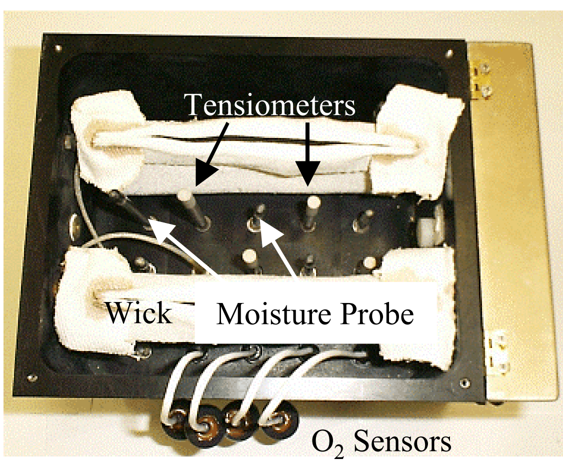

Figure 3: The top view of the inside of the Root Module, showing one of the sensor arrangements and the water wicking system.

The water distribution section on the right side of the RM contains two DC peristaltic Pumps. Three quick connectors are located on the bottom of the box, providing water into and out of the system. One line connects Pump 1 to the water tank, providing the water storage for the system. The pump 1 output is connected to water distribution lines that feed to the four porous tubes in the substrate container. Each pump is visible from the front side of the RM designated by the labels "PUMP 1" and "PUMP 2" and is equipped with a magnet that is monitored by hall-effect sensors mounted on the lower side of the pumps. Because the CR10X has only two pulse ports and the CM is built to handle two growth units, only one hall-effect sensor can be active at one time. A manual switch is provided to allow either pump to be monitored. Pump 2 is used to prime the differential pressure transducers. It can also be configured as a backup to Pump 1, should it fail during a growth experiment.

An air channel assembly consisting of an air channel and air channel cover is mounted on the top of the RM to contain the substrate, isolate the plant support wicks, and to provide an air inlet at the base of the leaf chamber. Two brackets on the air channel are used with latches on the leaf chamber to connect the two components. The air channel is designed with four air channels and two foliage growth channels. There is a channel on each side of the two foliage growth openings. The two foliage growth openings on the channel cover match those of the air channel. In the cover is a series of holes along each channel of the air channel. The diameter of the holes increases as air flows toward the farther end assuring even airflow to the LC.

Leaf Chamber

The Leaf Chamber (LC), see Figure 4) protects the plant vegetation and provides the physical connection between the RM and the LM. It is basically a hollow box tube, 25 cm in length, which can be easily exchanged to support shorter or taller plants. The LC reflects light back into the canopy and supports the canopy variable measurement system. Reflective film on the inside of the LC maximizes light use, reflecting it back to the plants. In the front side of the leaf chamber is a large Lexan window, also covered with a reflective tape, which can be opened to allow observation of plant foliage and collect samples. A latch on the window prevents inadvertent opening during transport.

<u>Light Module</u>

The light module sits at the top of the growth module above the LC. The front panel of the LM Figure 5) contains the fan and light operation switches. The design of the two locking switches inhibits inadvertent switching. Green LEDs mounted with the switches indicate the CR10X is controlling the respective device when the switch is in the “AUTO” position. In the “OFF” and “ON” position the device is manually turned off or on, respectively.

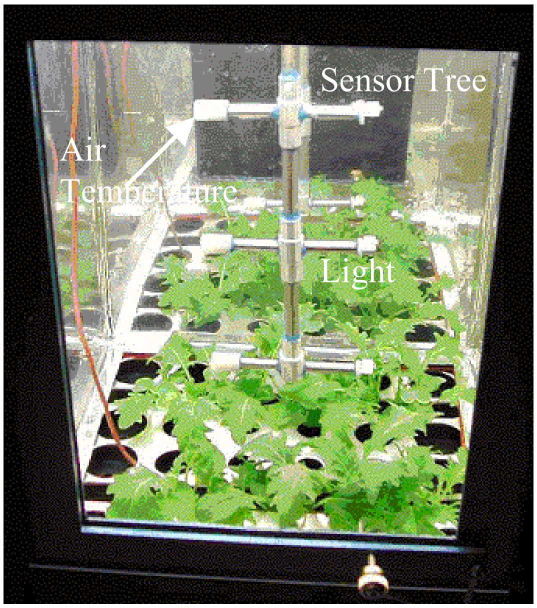

Figure 4: Lada Leaf Chamber containing two rows of Mizuna, the canopy temperature and light distribution measurement (sensor) tree.

Two 5cm fans are mounted on top of the LM. These fans pull air through the air channel assembly on the top of the RM, and up through the LC to provide controlled vertical flow ventilation to the plants. Fan activation is controlled by the CR10X when the “LIGHTS” switch is in the “AUTO” position. A third small fan is mounted on top of the sensor tree connector inside the module to aspirate the canopy air temperature sensors. The sensor tree provides PAR and canopy temperature at 3 levels, while a separate thermocouple measures the input air temperature at the bottom of the canopy. The temperature of the air exiting at the top of the canopy is measured using the thermocouple reference PRT probe on the bottom of the LM. Two, crew replaceable U-shape florescent lights are located in the LM (Figure 6) to illuminate the LC volume, They provide a PAR of over 230 μmol m^{-2} s^{-1} at the top of the RM to support initial plant growth, and are controlled by the CR10X when the “FANS” switch is in the “AUTO” position.

The light module contains a relative humidity sensor, an infrared leaf surface temperature sensor, a ballast temperature monitor, and the reference temperature sensor for the thermocouples used to measure the canopy environment. A USB camera is mounted at the bottom side of the LM and is controlled by the FIVA in the CM. This camera takes pictures of the foliage as specified by the user in the Lada Software System (LSS).

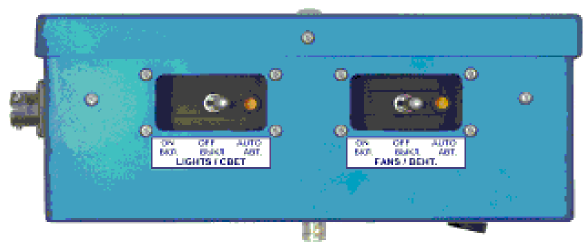

Figure 5: The front view of the Lada Light Module, showing the fan and light control switches.

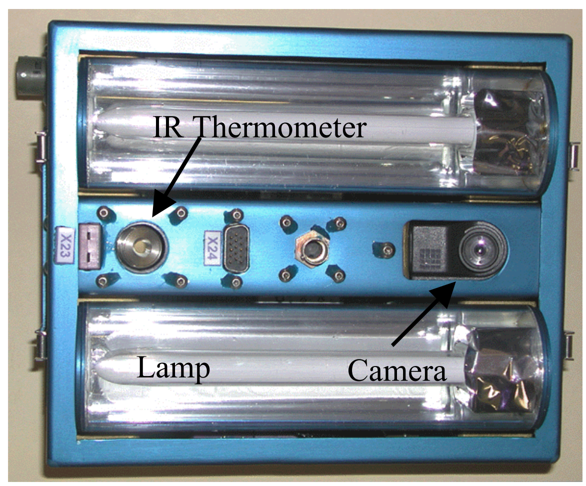

Figure 6: The Light Module, showing the lamps, sensors and interface connections and camera.

WATER TANK

The Water Tank (WT, see Figure 7) is a Lexan cylinder with two aluminum ends and two Teflon water bags. The internal bag connector bolts to the water tank end plate, and has a water feed tube that passes through to a protected quick connection. The bag is oversized that when filled with water it fills the cylinder and cannot burst. The WT is filled by a connecting tube to the ISS water supply or to an EDV storage volume using a single use sterilized adapter. Once filled, the WT is connected to PUMP 1 for normal operation or to PUMP 2 to prime the tensiometers.

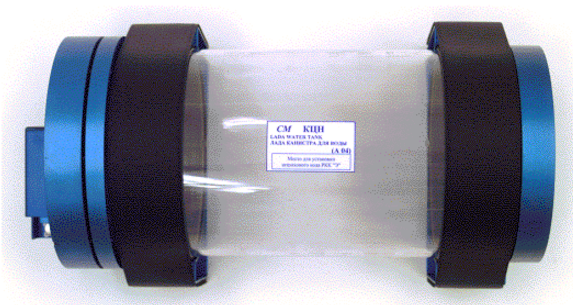

Figure 7: LADA Water Tank holds 5 liters of water and can be refilled from the ISS EDV system.

LADA CONTROL SYSTEM

Actuators on various hardware components and the Lada Software System (LSS) control the Lada greenhouse. Lada uses two computers to provide display, control, data acquisition, storage, and data communications. The interfaces between the computers and components are shown in Figure 8. The basic system storage for all software is the hard disk of the CM display unit. The CR-10X data collection and control software is downloaded to the CR-10X from the FIVA. Once installed on the CR-10X, they are battery backed in case of power failure. The CR-10X has limited channel input and control output capability, and

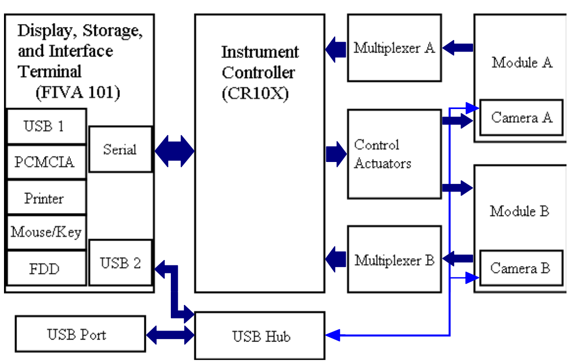

Figure 8: LADA control, data acquisition, and communications hardware schematic. The instrument controller (CR-10X) provides that actual data collection and control functions for Lada.

so two multiplexers and a Control Actuator card are used with the CR-10X to form the data collection and control functions. The Serial and USB 2 connectors are internal to the CM and provide interface links to the CR-10X and the cameras in the PCs.

LADA SOFTWARE SYSTEM

LSS provides a user-friendly interface to the Lada hardware. It guides the user through proper adjustment of the control set points and manipulation of greenhouse actuators. The software is used to set the environmental parameters that will be used by the CR10X in the CM to control the growth chamber(s) and monitor and save plant growth data. LSS allows the user to change all control parameters of the Lada greenhouse when Lada actuators are in AUTO mode and indicates which actuators are to be manually manipulated during various procedures. LSS allows for manual, software-manual, and automatic operation of the Lada greenhouse. LSS transfers parameters to the CR10X data measurement and control system, and downloads data from the CR10X to be displayed and saved to disk.

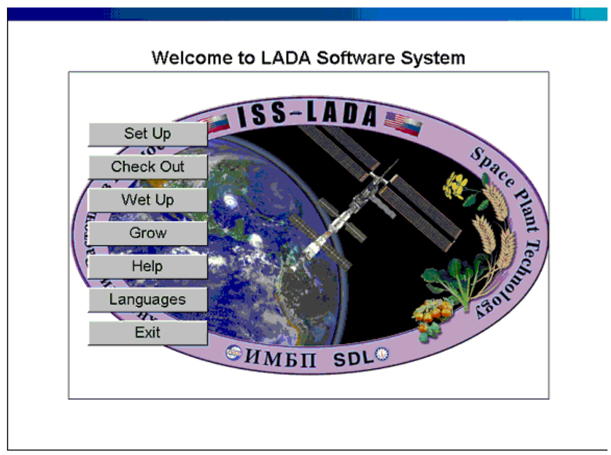

Figure 9: LSS Main Screen allows the user to select the major program modules.

LSS provides a user-friendly interface for the CR-10X controller. Plant growth archival files are saved to hard disk for transmission to ground controllers. LSS is also used for guiding the user through various procedures by providing visual and textual descriptions of steps to be performed within the procedures. When the display system boots up, the LSS main screen (See Figure 9) appears, providing primary functional options.

The Set Up module leads the crewmember through the installation procedure. Hard copy documentation is only required to apply power to the system. Once power is applied and the display unit is booted, the Set Up module provides to assembly and test instructions for the system.

<u>The Check Out Module</u> is used to check system function after Set Up has been completed. It tests and displays all of the system voltages, control functions, and makes initial measurements on all of the sensors. A tabular report is prepared at the end of the program, along with a picture from each of the cameras.

<u>The Wet Up Module</u> is used to wet the root module. The user can select the amount of water to be injected, and this module will inject small doses until that amount has been delivered. The substrate moisture sensors are read at regular intervals (20 minutes or every hour) to document the wet up processes. At the end of the wet up process, the data collected from the sensors and pump counts are stored to a data file that can be down linked for processes validation.

<u>The Grow Module</u> provides the readout and control interface for the plant growth period. It contains the main functionality of the program. Unlike the previous modules, which are essentially single string automatic processes that flow from step to step, the Grow button connects to another multi-threaded control and display interface screen. The functions provided by this screen are detailed in the next section.

<u>The Help Module</u> provides access to the onboard documentation system. This is a searchable text and picture document in HTML format, which provides the crew with system details, troubleshooting and operational instructions, as required.

<u>The Languages Button</u> toggles the display text for each button and message between Russian and English. This button provides a default option at the beginning of the program, and all following options are displayed in the selected language. The Language option can also be toggled anywhere in the system by a display unit function key.

THE GROW SCREEN INTERFACE

Pushing the “Grow” key on the initial welcome screen brings the user to the LSS main function user interface. This screen provides the user with all of the control options and variable displays required to set up and monitor plant growth in Lada. The “Grow” screen is shown in Figure 10.

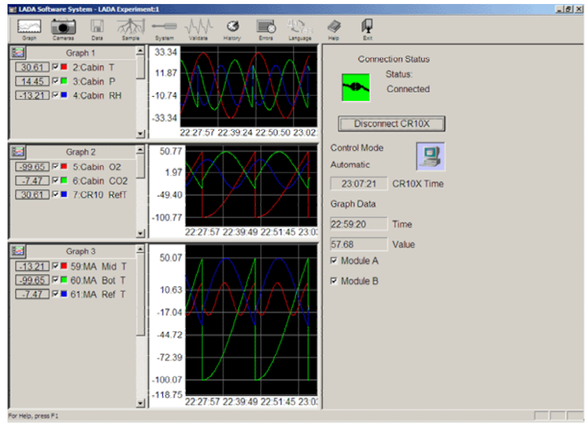

Figure 10: The “Grow” user interface screen in LSS.

The Grow interface provides several icons to activate pull down option windows, manages connection to the CR-10X instrument interface, and provides three graphical displays. The displays (white windows in Figure 10) operate as strip charts for the selected variables. An Icon Bar extends across the top, providing access to required system functions. These are (from left to right): The Graph icon (upper left) sets up the chart windows. The camera icon allows the crew person to take a manual picture and to view previously taken pictures. The Disk icon provides data transfer from the display hard disk to the microdrive or the Floppy. The Root icon controls the commands for manual substrate moisture sampling and displays the values from last automatic measurement. A Screwdriver icon provides a pull down window with buttons for all control functions. The History Icon shows the event file, for review of automatic and manual control events, while the Error Icon provides a text history of any software errors. The Language and Help buttons are the same as those on the Welcome screen, while the Exit icon returns the user to the Welcome screen. The windows to the right of the bottom chart provide digital chart values for the cursor position, and tells LSS how many and which chambers are attached, and the CR-10X time. This time window is useful to know if the charts are up to date.

EXAMPLE DATA

During the recently completed qualification test series, a crop of Mizuna was grown from seed to harvest at 20 cm tall. Lada was placed in the automatic control mode, with the set point adjusted between 85 and 90% for the growth period. Figure 11 shows example data for a portion of the test, showing a probe near the bottom, middle and top of the root module, along with one of the wick sensors. The top sensor showed more variability in its reading than the sensors that were lower in the substrate. As the canopy closed, the amount of water used by the crop increased dramatically, approaching 300 ml of water per day. As the rooting became more effective, the top substrate probe and the wick sensor moved closer to the same substrate moisture level.

CONCLUSIONS

Lada has completed its qualification testing and is nearly ready to ship to Russia for launch to the ISS. Under the Russian plan, it will remain on ISS, to support both crew "gardening" and scientific exploration. New root modules and supplies will be sent up as required, to meet program needs. One option being studied to minimize uplift requirement, is to use a longer life fertilizer in the root zone. This is currently under test in both Russia and the U.S. This would allow multiple crops to be grown in a single module, a technique that was first utilized in Svet. The experiments Greenhouse 4 and 5 (wheat) and Greenhouse 6 (salad) were grown in the same root module.

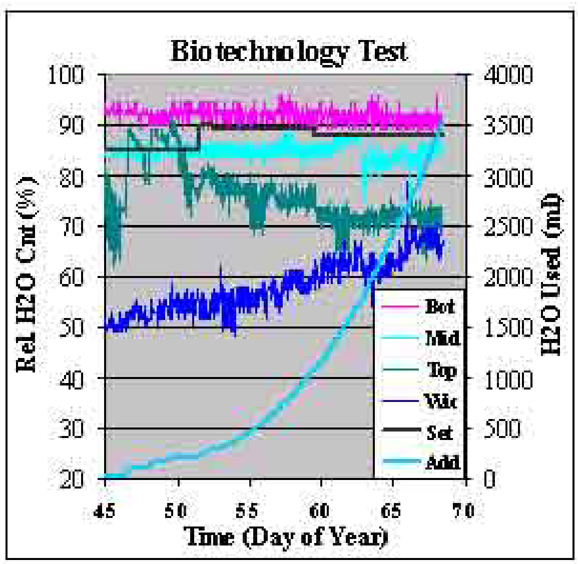

Figure 11: Substrate moisture control data from the Lada Biotechnology test.

A unique feature of the use plan will be allowing the crew to use Lada to grow vegetables for diet and recreational use when it is not being used for scientific experiments. All Russian crewmembers will be trained to operate Lada.

Figure 12: A 20 cm tall Mizuna crop, ready to eat.

For the first time, crew crop growing will not be a "bootleg" operation. In this respect, Lada will add a new aspect to plant μg research, the study of Crew – Plant interactions, including the psychological aspects. While we, in conjunction with the Russians have conducted several ground studies of the advantages of crew-plant psychological benefits, we know of no formal studies that have been conducted in space.

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