NASA FINAL TECHNICAL REPORT: NAG9-849

March 24, 1998

Title of Grant: Selection of Cultivars for use in Controlled Environment Life Support

System (CELSS) Human Rated Test Facility (HRTF) Trials.

Type of Report: Summary of Research: Final Technical Report

Principle Investigator: Robert W. Langhans

Graduate Student: David de Villiers

Period Covered: October 1, 1995 to March 31, 1997

Grantee: Cornell University Office of Sponsored Programs, 120 Day Hall, Cornell

University, Ithaca, NY 14853

Sponsor: Johnson Space Center, NASA

Grant Number: NAG9-849   (Cornell OSP# 29412)

Selection of Cultivars for use in Controlled Environment Life Support System (CELSS)

Human Rated Test Facility (HRTF) Trials:

NASA Final Technical Report (NAG 9-849)

March 24, 1998

This report is on work performed by David de Villiers for grant number NAG9-849, Selection of Cultivars for use in Controlled Environment Life Support System (CELSS) Human Rated Test Facility (HRTF) Trials. The grant preceded a three-year NASA fellowship. The aims under this training grant, as under the subsequent fellowship, were to elaborate the theory and technique of cultivar evaluation for specialized controlled environments, then to employ the technique on selected crops, ultimately conducting cultivar trials, and making the knowledge gained available for use in NASA's space program.

During the period of this report, David de Villiers took a number of courses necessary in preparation for writing his MS thesis (on the topic of vegetable crop cultivar evaluation). Courses taken included Plant Breeding, Statistical Methods, Physiology of Yield, Vegetable Crop Physiology, Plant-Plant Interactions, Principles of Biochemistry, and Quantitative Whole Plant Physiology; other courses were audited. Concomitant with course work, David undertook a comprehensive search of the Cornell agricultural library (Mann library) and its data-bases for any and all material relating to cultivar evaluation of vegetable crops, and also developed the logic of how to go about narrowing down the field of contending cultivars when undertaking cultivar trials. The results of this work, the principal outcome of the grant, are reflected in his MS thesis, particularly in Chapter 2 , "Commercial and Scientific Literature," and even more so in Chapter 8, "Selecting cultivars and lines for screening." David also attended annual conferences of vegetable crop plant breeders, annual yield trials and breeding trials for vegetable crops, as well as relevant professional conferences such as the ASHS annual meetings, and the Growth

Chamber meetings of NCR 101 and ASHS. Contacts developed with breeders at that time have proved to be of continued value for current research.

Largely due to the support provided by this grant and the subsequent NASA fellowship, David was able to write and defend his MS thesis, "Vegetable Cultivar Evaluation and Crop Selection for Controlled Environment Agriculture and Advanced Life Support Systems" in the spring and summer of 1997. This 176-page thesis is available through the Mann Library of Cornell University; copies have also been supplied to NASA personnel (Daniel J. Barta of JSC and Raymond E. Wheeler of KSC). The thesis can be used as a blueprint for crop selection and cultivar evaluation for all crops used in controlled environments, and is so being used in David's Ph.D. work. The Abstract is appended.

One of the major differences between cultivar selection for controlled environments and conventional agriculture is that in the former one is interested in productivity (yield over time), in the latter, yield irrespective of time. This makes time-of-harvest critical in the former case whereas it is not in the latter. It further implies that time-of-harvest needs to be optimized, and this in turn requires calculation of how cost of production changes with different harvest times. A second major difference is that environmental set-points need optimization in the case of controlled environment agriculture whereas they are a given in the conventional agriculture. Optimization needs to be in terms of cost of production: the key lies in the trade-off between capital cost of the production facility and efficiency of energy use. In highly capital-intensive operations such as Advanced Life Support Systems, cost of production is lowest when production is very intensive, even at the expense of energy-use efficiency. However, this is only within limits. A third major difference is that in crop production in life support systems, volume of space occupied in addition to area is critical, affecting the size of the facility needed and thus cost of production. Cultivars need to be short in addition to being highly productive. Several other differences are elaborated in the MS thesis.

Following completion of his MS, David spent six weeks as a summer intern at Johnson Space Center under the supervision of his NASA Technical Adviser, Daniel J. Barta, and his thesis chairman, Robert W. Langhans, on sabbatical leave at JSC at this time. The project assigned David was to investigate potential output of a modular Vegetable Production Unit, possibly to be incorporated in Mars Transfer, the Space Station, and other applications. The substantive outcome of this summer internship was a 42-page report on possibilities for such a module. Copies of this unpublished report reside with Daniel J. Barta and others at JSC. After returning to Ithaca Fall 1997 David commenced experiments on green bean and dry *Phaseolus* bean, and cultivar selection of these crops for use in the space program, putting into practice the precepts developed on the basis of this training grant. Several experiments are completed and more are currently under way. These will be more fully described in subsequent technical reports.

Appendix I

ABSTRACT (of MS thesis)

Cultivar evaluation for controlled environments is a lengthy and multifaceted activity. The chapters of this thesis cover eight steps preparatory to yield trials, and the final step of cultivar selection after data are collected. The steps are as follows:

1. Examination of the literature on the crop and crop cultivars to assess the state of knowledge.

2. Selection of standard cultivars with which to explore crop response to major growth factors and determine set points for screening and, later, production.

3. Determination of practical growing techniques for the crop in controlled environments.

4. Design of experiments for determination of crop responses to the major growth factors, with particular emphasis on photoperiod, daily light integral and air temperature.

5. Developing a way of measuring yield appropriate to the crop type by sampling through the harvest period and calculating a productivity function.

6. Narrowing down the pool of cultivars and breeding lines according to a set of criteria and breeding history.

7. Determination of environmental set points for cultivar evaluation through calculating production cost as a function of set points and size of target facility.

8. Design of screening and yield trial experiments emphasizing efficient use of space.

9. Final evaluation of cultivars after data collection, in terms of production cost and value to the consumer.

For each of the steps, relevant issues are addressed. In selecting standards to determine set points for screening, set points that optimize cost of production for the standards may not be applicable to all cultivars. Production of uniform and equivalent-sized seedlings is considered as a means of countering possible differences in seed vigor. Issues of spacing and re-spacing are also discussed.

In mapping crop response to growth factors, it is proposed that a first set of experiments examine daylength sensitivity and light intensity effects by holding daily light integral constant while varying photoperiod and light intensity. A second set of experiments would vary daily light integral at a fixed photoperiod appropriate to the crop to explore limits on productivity. Temperature would be varied in both sets of experiments.

For most vegetable crops, comparison of cultivars of different maturity date requires discovery of the yield function over the harvest period, from which can be ascertained when productivity is a maximum. At least three harvests timed to bracket the peak in productivity are advised.

Arguments are presented that the most likely and feasible source of superior materials for controlled environments will be from breeding lines currently under evaluation. Fast screening procedures are proposed to ascertain plant characteristics other than yield performance when information is lacking.

Set points for yield trials need to be those for production; appropriate set points cannot be determined without economic analysis of facility cost, labor cost, and cost of supplying inputs.

To economize on space needed for yield trials, I have proposed use of opaque, reflective side walls between cultivars and sample harvest units to replace guard rows and accommodate staggered harvests.

The cost of production index (COPI) is the single most important criterion for cultivar evaluation. For commercial CEA, final selection of cultivars requires market analysis additionally because the cheapest cultivar to produce may not be the best seller. For space life support, post-harvest processing costs need to be included with production costs. The value of superior quality and palatability in fostering well-being of colonists needs to be weighed against additional cost in providing it.

Crop selection for space colonies is addressed in the introductory and penultimate chapters. It is argued that crop selection should be guided from menu in addition to nutritional goals and minimization of cost.