**BARD Research Grant
Final Scientific Report**

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Project Title: Effects of root zone temperature, oxygen concentration, and moisture content on actual vs. potential growth of greenhouse crops

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Keywords *not* appearing in the title and in order of importance. Avoid abbreviations.

Calorimetry, Mathematical modeling

Abbreviations commonly used in the report, in alphabetical order:

Budget: IS: \$150,000

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Signature
Principal Investigator

Signature
Authorizing Official, Principal Institution

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Publication Summary (numbers)

	Joint IS/US authorship	US Authors only	Israeli Authors only	Total
Refereed (published, in press, accepted) BARD support acknowledged				
Submitted, in review, in preparation	2 (planned)			2
Invited review papers			1	1
Book chapters		1	1	2
Books	1 (in prep)			1
Master theses			1 (in prep)	1
Ph.D. theses		2 (in prep)		2
Abstracts	1	4		5
Not refereed (proceedings, reports, etc.)		3	3	6

Postdoctoral Training: List the names and social security/identity numbers of all postdocs who received more than 50% of their funding by the grant.

Amul Purohit,

Cooperation Summary (numbers)

	From US to Israel	From Israel to US	Together, elsewhere	Total
Short Visits & Meetings		3	1	4
Longer Visits (Sabbaticals)		(One planned for 2006)		0

Description Cooperation:

The cooperation focussed on developing information using calorimetry to develop information in support of a mathematical modeling project to quantify the effect of various root zone variables on plant processes. The model system for the mathematical modeling was cut-flower roses. The cooperation brought together our expertise on greenhouse rose production and calorimetry. Calorimetry work was done in both Israel and at UCDavis; the modeling work was done exclusively at UCDavis.

Patent Summary (numbers)

	Israeli inventor only	US inventor only	Joint IS/US inventors	Total
Submitted				0
Issued (allowed)				0
Licensed				0

Title: Effects of root zone temperature, oxygen concentration, and moisture content on actual vs. potential growth of greenhouse crops

PIs: J Heinrich Lieth, Michael Raviv and David W. Burger

Abstract

Soilless crop production in protected cultivation requires optimization of many environmental and plant variables. Variables of the root zone (rhizosphere) have always been difficult to characterize but have been studied extensively. In soilless production the opportunity exists to optimize these variables in relation to crop production.

The project objectives were to model the relationship between biomass production and the rhizosphere variables: temperature, dissolved oxygen concentration and water availability by characterizing potential growth and how this translates to actual growth. As part of this we sought to improve our understanding of root growth and rhizosphere processes by generating data on the effect of rhizosphere water status, temperature and dissolved oxygen on root growth, modeling potential and actual growth and by developing and calibrating models for various physical and chemical properties in soilless production systems. In particular we sought to use calorimetry to identify potential growth of the plants in relation to these rhizosphere variables.

While we did experimental work on various crops, our main model system for the mathematical modeling work was greenhouse cut-flower rose production in soil-less cultivation. In support of this, our objective was the development of a Rose crop model. Specific to this project we sought to create submodels for the rhizosphere processes, integrate these into the rose crop simulation model which we had begun developing prior to the start of this project. We also sought to verify and validate any such models and where feasible create tools that growers could be used for production management.

We made significant progress with regard to the use of microcalorimetry. At both locations (Israel and US) we demonstrated that specific growth rate for root and flower stem biomass production were sensitive to dissolved oxygen. Our work also identified that it is possible to identify optimal potential growth scenarios and that for greenhouse-grown rose the optimal root zone temperature for potential growth is around 17 C (substantially lower than is common in commercial greenhouses) while flower production growth potential was indifferent to a range as wide as 17-26C in the root zone. We had several set-backs that highlighted to us the fact that work needs to be done to identify when microcalorimetric research relates to instantaneous plant responses to the environment and when it relates to plant acclimation.

One outcome of this research has been our determination that irrigation technology in soilless production systems needs to explicitly include optimization of oxygen in the root zone. Simply structuring the root zone to be "well aerated" is not the most optimal approach, but rather a minimum level. Our future work will focus on implementing direct control over dissolved oxygen in the root zone of soilless production systems.

Achievements

Greenhouse crop production is a segment of agricultural production where the opportunity exists to control and optimize all facets of plant and crop growth. The focus of the work in this project is on the root-zone and how its manipulation affects crop production.

Over the time that greenhouses have been used in agriculture, a lot has been learned and implemented into a package of horticultural information that is the current state-of-the-art in greenhouse production. The actual degree to which horticultural technology is implemented is generally a factor of economic feasibility driven by local marketing objectives. As such, full greenhouse automation is feasible in northern Europe where labor costs dictate as much automation as possible, while in other areas implementing full automation may not be economically feasible. One facet of greenhouse production that has been the focus of optimization is the root zone, through the development and use of substrates which generally do not include any field soil. "Soilless" production is universal in greenhouse agriculture and it is the focus of this project.

Advances in this area of agriculture require that we obtain a better understanding of the response of the plants to the rhizosphere. Our approach has been to attempt to build mathematical models to describe various rhizosphere characteristics and plant processes and to develop these in such a way as to be suitable for use in greenhouse management. The focus of the research has been the following areas:

1. Effect of specific root zone variables on the growth of our model system crops (especially rose)
2. Exploration of the concept of "potential growth" and how the soilless production system achieves "actual growth".
3. Development of crop models, particularly for greenhouse crops such as Rose

We have made the following progress in these areas.

Effect of specific root zone variables on the crop growth

Our work in studying the root zone of soilless production systems includes both specific variables as well as attempt to better understand the entire soilless production system (Appendix A-2).

With regard to specific root zone variables we have made significant advances in the area of measuring root zone salinity and dissolved oxygen. Prior to the start of the project the only technology in use for measuring dissolved oxygen in the root zone solution were sensors and instruments based on membranes of specific permeability to oxygen. We found that we could use spectrophotometric technology. This allowed us to show that available oxygen declines quite rapidly in the root zone of substrates that are not highly aerated.

At both locations (Israel and US) we demonstrated that specific growth rate (RSG) for root and flower stem biomass production were sensitive to dissolved oxygen.

Development of instrumentation technology for monitoring the root zone was a key element to being able to do the research of this project. This work is continuing as we refine the various methods.

Our collaboration during this project involved an outreach project to provide information about soilless production to growers who need this information. During the project period this resulted in a book on hydroponic (i.e. soilless) production (Appendix A-3). We have also published a review article reviewing the various physical factors that define the root zone, with a special emphasize on two of the main aspects of the project: water and oxygen availabilities. Our collaboration in this area is continuing (by Drs Raviv and Lieth) as we aim to write/edit the definitive scientific reference book on soilless production.

Potential versus Actual Growth

One of the key elements of our collaboration was our approach involving the use of calorimetry to explore the notion of “potential growth” with respect to physical properties of the root zone (Appendix A-1). Our original hypotheses during this research project were that: (1) Improvements in the rhizosphere, particularly in relation to dissolved oxygen concentration and temperature, can lead to substantial increases in crop productivity and (2) that calorimetry provides a way of estimating potential root growth. Both of these hypotheses were confirmed so that calorimetry was indeed found to be a useful tool in predicting potential root growth.

Our achievements in the use of calorimetry to estimate the specific growth rate of various rose tissues resulted in advances as well as set-backs. Excellent calorespirometric data were collected from 1-cm rose root sections from plants grown at rhizosphere temperatures between 10 and 30 C. These data allowed us to predict that the greatest specific growth rate for rose roots occurred at about 17.5C.

Specific details on the calorimetry work are included in appendices A-9 and A-10. Using calorimetry to follow metabolic changes in rose leaflets in response to increased soil moisture tension (reduced soil moisture content) was problematic. We were unable show any changes in metabolic heat rate or respiration rate of rose leaflets as soil moisture conditions changed. While disappointing, this finding focused attention on perhaps a central question to the use of microcalorimetry for studying basic plant metabolism and response to the environment: Do calorespirometric data relate to instantaneous processes of the plant or acclimated processes requiring changes in the plant's basic metabolism? Prior to the start of the project we had a considerable body of work showing that calorimetry allowed us to measure instantaneous responses. However, during the course of the project we encountered several situations where tissue responses (in terms of heat production and respiration) were not what we had seen in previous work. Reasons for this discrepancy are few, but may include differences in plant age, size and/or genotype. Thus the predominant differences were due to acclimatization.

One of the most significant results of this work has been to provide more specific focus on the role microcalorimetry in scientific research.

Crop Modeling Research: Cut Flower Rose Model

The rose crop modeling work made significant advances in a number of areas. While the experimental research on this project focused primarily on root zone variables, implementation of such information in a whole-plant model requires a fairly complete implementation of such growth processes as photosynthesis, respiration and carbohydrate partitioning. Prior to the start of this project we had already implemented a rudimentary model. During the period of this project we enhanced the model as to its representation of photosynthesis and stomatal behavior (Appendices A-4 and A-6), stem elongation as affected by salinity (Appendix A-5) and nutrient uptake (Appendices A-7 and A-8). Other root-zone process modeling work is on-going and expected to lead to publications in the future.

While the primary factors of study in this project were temperature, moisture content and oxygen availability, these basically drive the plant system through nutrient uptake, water uptake and root growth. Our continuing collaboration in the area of mathematical modeling of the root zone has expanded to focus on how these variables affect nutrient uptake of both primary and secondary nutrients. Furthermore, the collaboration has been expanded to include other Israeli scientists as well as scientists from Korea.

One of the most significant achievement of the project has been our determination that irrigation technology in soilless production systems needs to explicitly include optimization of oxygen in the root zone. In the past it was felt that it was adequate to have a root zone composed in such a way as to be “well aerated”. We have observed cases where even in “well aerated” media oxygen availability can become suboptimal. One reason this was not noted before was due to the fact that suboptimal levels of oxygen do not result in visible symptoms unless the concentration falls below a specific critical level.

This project would not have been possible without the collaboration of the international researchers on this project. Both of our groups had a number of difficult hurdles and our collaboration help us find ways to solve these problems. It should be noted that our work on this project also set the stage for additional collaborative work in relating calorimetric information to practical decision make and was also the seed for a much larger project on assembling a definitive book on soilless production (in preparation).

Publications bearing BARD acknowledgment are not yet in press.

Appendix - Table of Contents

Appendix item	Citation or report title
A-1	Raviv,M., J. H. Lieth, D.W. Burger and R Wallach, 2001. Optimization of transpiration and potential growth rates of cut rose (CV. Kardinal) with respect to root-zone physical properties. Journal of the American Society of Horticulture Science.126(5):638-643.
A-2	Raviv, M., Wallach, R. and T.J. Blom (2004). The effect of physical properties of soilless media on plant performance - A Review. Invited lecture. Acta Hort. 644: 251-259
A-3	Raviv, M., Wallach, R., Silber A. and A. Bar-Tal, 2002. Substrates and Their Analysis. pp. 25-102, Chapter 2 in: Savvas, D. and H. Passam (eds.), Hydroponic Production of Vegetables and Ornamentals. Embryo Publications, Greece.
A-4	Kim, S.-H. and J. H. Lieth. 2001 Modeling diurnal variation of whole-plant photosynthesis of greenhouse roses. In: Zieslin, N. and H. Agbari (Eds.) Proceedings of the Symposium on Rose Research and Cultivation.
A-5	Oki, L.R. and J.H. Lieth. 2004. Effect of Changes in Substrate Salinity on the Elongation of Rosa hybrida L. 'Kardinal' Stems. Scientia Horticulturae 101:103–11.
A-6	Kim S.H. and J.H. Lieth, 2003. A Coupled Model of Photosynthesis, Stomatal Conductance, and Transpiration for a Rose Leaf (Rosa hybrida L.). Annals of Botany 91:771-781.
A-7	Silberbush, M. and J.H. Lieth, 2004. Nitrate and potassium uptake by greenhouse roses (Rosa hybrida) along successive flower-cut cycles: a model and its calibration. Scientia Horticulturae 101: 127–141.
A-8	Mattson, Neil, Robert Flannery and Heiner Lieth, 2004. Development of a Model for Rose Productivity. Bulletin of the International Cut Flower Growers Association. Sep 2004
A-9	Michael Raviv*, Hamam Ziadna and Shlomit Medina 2005. BARD Project: Third year report – Israeli part
A-10	Dave Burger, Amul Purohit, and Heiner Lieth, 2005. BARD Project: Third year report - Calorimetry work at UCDavis