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Project Title:

Application of Turbulent Transport Techniques for Quantifying Whole Canopy Evapotranspiration in Large Agricultural Structures: Measurements and Theory

Investigators

Institutions

Principal Investigator (PI): Josef Tanny

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Keywords: Eddy covariance, screenhouse, turbulent flux, energy balance, modeling.

Abbreviations commonly used in the report, in alphabetical order:

EC – Eddy covariance

Budget: IS: \$ 142,000

US: \$ 153,000

Total: \$ 295,000

Signature
Principal Investigator
Appendix G6a

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	1	35	2	
Submitted, in review, in preparation	1		3	
Invited review papers			1	
Book chapters			1	
Books				
Master theses			1 (in progress)	1
Ph.D. theses			1 (in progress)	1
Abstracts			2	
Not refereed (proceedings, reports, etc.)				

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

Mario Siqueira, Post-doctoral researcher (currently at University of Brazilia, Brazil),
SS number: 646-20-9660.

Cooperation Summary (numbers)

	From US to Israel	From Israel to US	Together, elsewhere	Total
Short Visits & Meetings	1	1	2 (San Francisco, CA, Boulder CO)	4
Longer Visits (Sabbaticals)				

Description Cooperation:

Patent Summary (numbers)

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

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Abstract

Original objectives and revisions

The original objectives of this research, as stated in the approved proposal were:

1. To establish guidelines for the use of turbulent transport techniques as accurate and reliable tool for continuous measurements of whole canopy ET and other scalar fluxes (e.g. heat and CO₂) in large agricultural structures.
2. To conduct a detailed experimental study of flow patterns and turbulence characteristics in agricultural structures.
3. To derive theoretical models of air flow and scalar fluxes in agricultural structures that can guide the interpretation of TT measurements for a wide range of conditions.

All the objectives have been successfully addressed within the project. The only modification was that the study focused on screenhouses only, while it was originally planned to study large greenhouses as well. This was decided due to the large amount of field and theoretical work required to meet the objectives within screenhouses.

Background

In agricultural structures such as screenhouses and greenhouses, evapotranspiration (ET) is currently measured using lysimeters or sap flow gauges. These measurements provide ET estimates at the single-plant scale that must then be extrapolated, often statistically or empirically, to the whole canopy for irrigation scheduling purposes. On the other hand, turbulent transport techniques, like the eddy covariance, have become the standard for measuring whole canopy evapotranspiration in the open, but their applicability to agricultural structures has not yet been established. The subject of this project is the application of turbulent transport techniques to estimate ET for irrigation scheduling within large agricultural structures.

Major conclusions and achievements

The major conclusions of this project are: (i) the eddy covariance technique is suitable for reliable measurements of scalar fluxes (e.g., evapotranspiration, sensible heat, CO₂) in most types of large screenhouses under all climatic conditions tested. All studies resulted with fair energy balance closures; (ii) comparison between measurements and theory show that the model is capable in reliably predicting the turbulent flow characteristics and surface fluxes within screenhouses; (iii) flow characteristics within the screenhouse, like flux-variance similarity and turbulence intensity were valid for the application of the eddy covariance technique in screenhouses of relatively dilute screens used for moderate shading and wind breaking. In more dense screens, usually used for insect exclusions, development of turbulent conditions was marginal; (iv) installation of the sensors requires that the system's footprint will be within the limits of the screenhouse under study, as is the case in the open. A footprint model available in the literature was found to be reliable in assessing the footprint under screenhouse conditions.

Implications, both scientific and agricultural

The study established for the first time, both experimentally and theoretically, the use of the eddy covariance technique for flux measurements within agricultural screenhouses. Such measurements, along with reliable theoretical models, will enable more accurate assessments of crop water use which may lead to improved crop water management and increased water use efficiency of screenhouse crops.

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Achievements

Significance of main scientific achievements or innovation

The area of agricultural crops grown under screens and in screenhouses is constantly increasing. While irrigation requirements for crops in the open are relatively well established for most crops in many regions of the world, there is a significant lack of knowledge gap related to irrigation requirements for protected crops. This knowledge gap can be bridged through reliable measurements and modeling of evapotranspiration in protected environments. The Eddy Covariance (EC) technique, widely used for measurements of evapotranspiration and other scalar fluxes in the open, has never been established for the semi-open environment of protected crops, mainly screenhouses. The major innovation of this research is that this technique can reliably measure scalar fluxes in screenhouses.

The scientific significance of this result lies within the general practice in using the eddy covariance technique for the open. Usually, a set of criteria is applied to verify the suitability of the turbulent flow characteristics and physical terrain for adequate application of this technique. The present study showed that in the screenhouse environment, even though some of these criteria are only marginally valid, or even slightly deviate from the common literature standards, the fluxes measured by the EC technique are valid. This was verified through independent energy balance closure analysis and comparison with evapotranspiration models and the applied irrigation.

Furthermore, it was demonstrated that within the screenhouse environment, some of these validation criteria are somewhat modified, presumably due to the air flow modification by the porous screen. For example, the expressions of developed turbulent flow, based on the flux-variance similarity theory, are somewhat modified within the screenhouse than those in the open. Another example is the friction velocity which is sometimes lower than the values commonly measured in the open.

Another significant finding of this study is that the well known property of the surface layer, namely, the constancy of fluxes with height above the ground, is also nearly valid within the screenhouse, in the air gap between the horizontal screen and the plants' tops. This was demonstrated for water vapor, sensible heat, CO₂ and momentum fluxes by measuring

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simultaneously at two levels. This is another finding which demonstrates the suitability of the EC technique in this semi-open environment.

Via a newly developed higher-order closure model, the effect of a screen on the mean flow field, turbulent stresses, radiative and energy fluxes, as well as scalar sources, sinks, fluxes, and mean concentration within screen houses are explored. The model results for the screenhouse are presented and referenced against their 'open canopy' counterpart. The effects of the screen on the radiative properties were tested by the U.S. team, and the model flow field was calibrated against the EC measurements collected by the PI in Israel. Based on these model results, we found that the radiation modulation by the screen had the most significant effect on reducing sensible-heat. However, modeled reductions in latent-heat fluxes were primarily due to the intervention of the screen on the turbulent flow. The CO₂ dynamics within the screen-house is significantly affected by both - radiation and momentum exchange modulations by the screen. In general, the presence of a screen resulted in warmer and more humid environment inside the screen house consistent with the experiments. This altered microclimatic state was shown to promote reductions in both assimilation and transpiration. However, the overall effect of the screen was to enhance the modeled water use efficiency thereby resulting in water savings for the same amount of gross primary production. The model testing with the EC for sensible heat, CO₂, and water vapor as well as further refinements of the physiological and aerodynamic properties is the subject of a new BARD proposal that builds on these developments.

All these results suggest that the EC technique is capable of reliable flux measurements in a wider range of conditions than previously established in the scientific literature. The results further suggest some modifications of the validity criteria which may expand the use of this technique for environments and/or conditions previously considered as unsuitable for such measurements. This conclusion has a more general significance, outside the original scope of the present project.

Agricultural and/or economic impacts of the research findings

From the agricultural viewpoint, the possibility of using the EC technique for reliable flux measurements in protected environments, along with the theoretical model which enables flux predictions under specific conditions will be most significant for improving the irrigation

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management and consequently the water use efficiency. This issue is of utmost significance mainly due to the expected water shortage in many regions of the world. The project has demonstrated that the EC system allows a continuous long-term measurement of whole canopy evapotranspiration and CO₂ flux in screenhouses. The ratio between these two parameters constitutes the concept of water use efficiency, namely, the amount of water required by the plant in order to perform photosynthesis at a certain rate. Knowledge of this parameter during the whole growth cycle of the crop may direct the farmer attention to periods with higher or lower water use efficiency. Such knowledge, which is almost totally unavailable with present monitoring systems, might lead the grower to a better irrigation management which will eventually maximize the water use efficiency.

The validity of using the EC technique in screenhouses supports the use of simpler techniques for flux measurements which also belong to the family of turbulent transport techniques. Methods like the Surface Renewal, Flux-Variance, Half-order Time Derivative and Bowen Ratio, whose instrumentation needs and operational demands are not as elaborate as the eddy covariance, may be applied in large screenhouses or greenhouses after proper calibrations and adaptations (as described in a recently submitted continuation BARD proposal). These techniques may be used on a day-to-day basis by the experienced grower or extension service expert for real-time measurements of evapotranspiration.

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Details of cooperation

The close cooperation between the two research teams, including mutual visits and meetings, significantly promoted the research objectives. This was evident throughout the project starting from the preparation of the original research proposal through the research work and finally in preparing this final report.

In particular, the setup of the two measurement systems within the screenhouse, aimed at exploring vertical gradients in fluxes, was mutually designed by the two teams. This proved to be a key parameter for the successes of the project in illustrating the fact that essentially, the fluxes within the screenhouse are constant with height provided sufficient fetch is available.

The PI (Tanny) and co-PI (Katul) met three times during the course of the project period: The first meeting took place in an international workshop at Boulder Colorado (October 2006) just at the beginning of the project. This allowed the two PIs to discuss some experimental results of screenhouse measurements which were already available with Tanny.

The second meeting took place when Tanny visited Katul at Duke University, on October 2008. This meeting allowed the two PIs to discuss more deeply the results of two additional field experiments conducted in Israel during 2007 and 2008. In that meeting, the model details were also discussed with Dr. Siqueira, a Post-Doc with prof. Katul supported by BARD, and all experimental information required by Katul for the model development was directly supplied by Tanny. Indeed, this meeting significantly promoted the model development in the US and its close relation to the field experiments in Israel. The meeting led to an experimental study in Duke, where the radiation properties of samples of agricultural screens (supplied by Tanny) used in the field studies in Israel, were measured. The meeting was also devoted to a further design of experiments aimed at better understanding the effect of the screen on the turbulent flow. Hence, the outcome was an additional field experiment, where two EC systems were deployed simultaneously, one above and one below the screen.

The third meeting between the two PIs took place in December 2010, during the AGU meeting in San-Francisco. This meeting was aimed at discussions and preparations of mutual scientific papers. One mutual paper is currently under preparation.

A visit of Dr. Mario Siqueira in Israel, took place on spring 2009. Dr. Siqueira was in charge of executing the modeling tasks at Duke University, under the guidance of Prof. Katul.

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During this visit Dr. Siqueira was able to directly observe a field campaign that was just under operation at the Carmel coastal region in Israel. This allowed him to closely realize the physical aspects of the screenhouse environment and certainly contributed significantly to the high coupling between the modeling and field measurements tasks.

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List of Publications

(Peer reviewed, BARD acknowledged)

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