University of Southern Queensland

Measurements of evaporation during sprinkler irrigation

A dissertation submitted by

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ABSTRACT

The availability of water for irrigated agriculture is a concerning issue in the world especially in arid and semi-arid regions. Irrigators are facing a number of challenges, including reductions in the availability of water and increased competition with industrial and domestic uses. Irrigated agriculture is the largest water consumer all over the world as well as in Australia, and there is pressure to increase water use efficiency. Efficient utilization of water can improve the crop production per unit of water applied and can contribute to water conservation. Among the irrigation systems, sprinkler irrigation is one of the most popular methods for achieving high application efficiencies. However, the irrigators are still less interested to adopt this system due to the lack of accurate information regarding the losses in sprinkler irrigation often citing high evaporation losses along with high cost of operation.

Evaporation losses during sprinkler irrigation are still a vital issue to the irrigation community all over the world. Previous experimental results have shown that they may vary from 0 to 45% of the applied water and that a large proportion of the loss is droplet evaporation in the atmosphere. However, recent theoretical studies reported that the total losses should not be much more than a few percent. They also suggested a negligible (less than 1%) amount of droplet evaporation compared to the major canopy evaporation component. Due to the limitations of the existing methodology and technique these theoretical results could not be verified by field experiments in real crops. Accurate estimates of the losses are important to determine the strategies for the optimal design and management of sprinkler irrigation systems as well as irrigation scheduling considering the application efficiency of the system. It is also important to provide the accurate information regarding the evaporation losses which can significantly help farmers to choose a suitable irrigation system. The relatively recent development of the eddy covariance (ECV) technique has

provided the opportunity to overcome the limitations of the existing methods to measure the evaporation during sprinkler irrigation. Therefore, this work aimed to measure the additional evaporation that occurs during sprinkler irrigation adopting eddy covariance technique and to separate its components in conjunction with additional measurements. In this regard, three research objectives were identified including: (i) use the eddy covariance (ECV) technique to measure the total evapotranspiration (ET) during sprinkler irrigation; (iii) partition the total evaporation into its major components during irrigation and subsequent periods; and (iii) to demonstrate how the ECV-sap flow data can aid in management of sprinkler irrigation.

The ECV system is consists of a fast-response three dimensional sonic anemometer coupled with open path infrared gas analyser. Sap flow was measured using six dynagauge sap flow sensors each with a digital interface, a hub and a data logger. Additional measurements include net radiation using a four component net radiometer, soil heat flux (*G*) using heat flux plates temperature and relative humidity using two temperature and relative humidity probes and the crop canopy temperature using an infrared thermometer. A fixed sprinkler irrigation system was installed in a way to make a circle of 50 m with an area of 0.2 ha for all trials. Experimental measurements were conducted over a range of surfaces from bare soil to different stages of crop throughout the period 2010-11 at the agricultural experimental station at University of Southern Queensland, Toowoomba, Australia.

Preliminary measurements were conducted over the grass and bare soil to evaluate the capability of the ECV technique to measure the total ET during sprinkler irrigation. The preliminary measurements showed that the ECV technique successfully measured the increased ET during irrigation and the decreasing rate of ET during post irrigation drying period. Using the nondimensional (ET_{ecadj}/ET_{ref}) values of ET, the average additional evaporation over the grass was estimated as 32%. The decreasing trend of ET over the time post irrigation was an indication of evaporation of the intercepted water from the grass surface. However, in case of bare soil the actual ET pre irrigation was well below the reference ET and increased to equal to the reference ET during the irrigation. In terms of nondimensional ET about 27% additional evaporation occurred over the bare soil during irrigation due to the increased soil moisture. Similar values of nondimensional ET post and pre irrigation illustrates that there was no intercepted water to evaporate on the surface in the case of bare soil.

Accordingly, a series of experimental trials were conducted over cotton at various growth stages, introducing the eddy covariance-sap flow method to measure the total evapotranspiration and sap flow. Nondimensionalisation of these measurements using ET_{ref} gave idealized curves of the total evapotranspiration and sap flow for each stage, i.e pre-, during and post-irrigation, which permits calculation of the additional evaporation caused by irrigation and suppression of transpiration. These calculations showed that the greatest effect of overhead sprinkler on water losses was the significant increase of ET as mostly canopy evaporation and reduction in sap flow due to the wetness of the canopy. The amount of additional evaporation varied significantly with crop canopy condition and climatic factors especially advection.

The significant increase of total ET from partial canopy to full canopy indicates that canopy evaporation was higher in full canopy due to the greater area of canopy surface in full crop canopy condition and hence greater interception capacity. This result supported the conclusion that canopy evaporation was the dominant component in sprinkler irrigation. Higher rate of ET measured during irrigation in advective conditions, indicates that advective conditions can increase the additional evaporation in sprinkler irrigation substantially on the basis of climatic conditions especially wind speed. The additional evaporation due to irrigation using impact sprinklers varied from 37% at partial canopy condition to 80% at full canopy condition. Adevctive conditions increased this additional amount by 12% to 20% depending on the climatic conditions.

It was shown how the total canopy evaporation can be subdivided into its different components including additional evaporation during irrigation and canopy interception capacity using idealized nondimensional ET and sap flow. However, the droplet evaporation could not be separated due to the limitations of the instruments used under this study.

It was also shown how the ECV-sap flow data can be used to predict the magnitude of additional evaporation for different regions in various operating and climatic conditions. This can aid the irrigators to predict the additional evaporation in sprinkler irrigation at any region for different time, climatic and operating conditions.

The results showed that canopy evaporation including droplet evaporation during irrigation is the dominant component (about 80%) in additional evaporation followed by the canopy interception (about 20%). The average amount of additional evaporation would be about 6% of applied water under normal conditions and about 8% in advective conditions in major cotton growing areas in Australia. It means that irrigators in those places may need to apply 6-8% of additional water.

CERTIFICATE OF DISSERTATION

I certify that the ideas, experimental work, results, analyses and conclusions reported in this dissertation are entirely my own effort, except where otherwise acknowledged. I also certify that the work is original and has not been previously submitted for any other award, except where otherwise acknowledged.

Endorsement:

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Md Jasim Uddin, Candidate **Date**

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Dr. Joseph Foley, Associate Supervisor **Date**

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I would like to dedicate this thesis to my late parents who taught me more in life than anyone else and who would be thrilled beyond words to see their son submit this dissertation for PhD degree.

ABBREVIATION

ABS	Australian Bureau of Statistics
AE	Available energy
Agplot	Agricultural Experimental Station
AI	Advection index
BR	Bowen Ratio
CNF	Cumulative normalized contribution
DOY	Day of year
EBR	Energy balance ratio
EC	Electrical conductivity
ECV	Eddy covariance
EF	Model efficiency
ET	Evapotranspiration
ET_{ec}	Unadjusted actual evapotranspiration measured by eddy covariance
ET_{ecadj}	Adjusted actual evapotranspiration measured by eddy covariance
ET_{ref}	Reference evapotranspiration
FoES	Faculty of Engineering and Surveying
F	Sap flow
GM	Genetically modified
HB	Heat balance
HPV	Heat pulse velocity
IRGA	Infrared Gas Analyzer
Irri	During irrigation period
MBE	Mean bias error
NCEA	National Centre for Engineering in Agriculture
NSW	New South Wales
Post	After irrigation
Pre	Pre/Before irrigation
RH	Relative humidity
R_{et}	Nondimensional number of evapotranspiration
R_f	Nondimensional number of sap flow
RMSE	Root mean square error
T	Transpiration
T_a	Air temperature
T_c	Canopy temperature
λE	Latent heat flux
λE_{adj}	Adjusted latent heat flux
USQ	University of Southern Queensland
VPD	Vapour pressure deficit
WDEL	Wind drift and evaporation losses
WS	Wind speed

PUBLICATIONS ARISING FROM THIS RESEARCH

Uddin, J., Smith, R., Nigel, H., & Foley, J. (2010). Droplet evaporation losses during sprinkler irrigation: an overview. *One Water Many Future, Australian Irrigation Conference and Exhibition*, Sydney, 8-10 June.

Uddin, J., Smith, R., Nigel, H., & Foley, J. (2010). Evaporation losses during sprinkler irrigation measured by eddy covariance technique. *One Water Many Future, Australian Irrigation Conference and Exhibition*, Sydney, 8-10 June.

Uddin, J., Smith, R., Nigel, H., & Foley, J. (2011). Evaluation of sap flow sensors to measure the transpiration rate of the plants during sprinkler irrigation. *Paper presented at the conference Society for Engineering in Agriculture (SEAg)*, Gold Coast, Australia, 29-30 September.

Uddin, J., Smith, R., Nigel, H., & Foley, J. (2011). Eddy covariance measurements of the total evaporation during sprinkler irrigation-Preliminary results. *Paper presented at the conference Society for Engineering in Agriculture (SEAg)*, Gold Coast, Australia, 29-30 September.\

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