DEVELOPING AN IMPROVED METHOD TO MONITOR AND PREDICT CROP WATER REQUIREMENTS

J. Styles[1], R. Stevens[1], H. Cleugh[2], C. Ewenz[3], G. Grigson[1], G. Scrale[3]

[1]South Australian Research and Development Institute, PO Box 411, Loxton SA 5333
[2]CSIRO Marine and Atmospheric Research, GPO Box 3023, Canberra ACT 2601
[3]South Australian Research and Development Institute, GPO Box 397, Adelaide SA 5001

ABSTRACT

Australia's water resources are being tested by extended drought and are likely to come under increased pressure with future climate change. This paper reports on a project to measure crop water use (evapotranspiration: ET) in a Riverland vineyard to assess and improve upon water use monitoring and prediction methodology currently available to irrigators. The findings will provide information for irrigation scheduling strategies to optimise irrigation efficiency and prevent deep drainage while maintaining crop productivity.

Our data indicate that soil moisture status is likely to be an important influence on crop water use both in the growing and non-growing seasons in the Riverland. In contrast, a similar study in a Padthaway vineyard showed that evapotranspiration varied more consistently with atmospheric conditions, and demonstrated a physiological response to high vapour pressure deficit. These results suggest that use of a reference or potential evapotranspiration based on weather conditions may be more applicable in climates or regimes that are not strongly water-limited. In low precipitation regions that are also subject to restrictions on water allocations, estimation of crop ET based on reference or potential ET will likely benefit from incorporation of information on soil moisture status and applied water. This study presents a generalised approach based on these findings to determine the annual course of crop water requirements in real time at weekly or greater resolution in order to guide irrigation scheduling and allow reliable accounting of crop water use at the farm and district level.

INTRODUCTION

Drainage from irrigated crop regions increases saline inflows into the River Murray. While management practices are changing to reduce this impact, there remains a need to develop more reliable and practical methodology to account for water used at the farm and district level and to minimise drainage. Current best practice in irrigation scheduling to meet crop requirements and minimise drainage makes use of a measure of evaporative demand calculated from weather data and application of modifying factors specific to crop type and growing stage, with some adjustment to account for soil moisture status. This study addresses weaknesses in the current methodology by collecting direct observational data on crop water use at the block scale and using it to validate an improved model of the important processes driving variability in crop water use. Climate and soil characteristics are measured concurrently and used to develop model parameterisation. Results, including improved modelling capability and understanding of crop water requirements, will provide a means to guide management decisions by individual irrigators as well as enable reliable monitoring of water use, drainage and implications for regional salt inflows to the River Murray.

In mid-February 2007, flux, meteorological and soil instrumentation were installed in a Chardonnay wine grape block and an automated weather station in a nearby paddock in the Riverland. The flux instrumentation provides continuous measurements of vineyard evapotranspiration (ET) and net ecosystem carbon exchange (NEE) at half-hourly resolution. Combined with concurrent climate, soil and sap flow measurements, the data demonstrate the relative influence on crop water use of factors including: (i) weather-dependent evaporative demand as it changes with wind speed, humidity, temperature, and solar radiation; (ii) soil moisture status as it responds to irrigation and precipitation inputs, evaporation, transpiration and drainage; and (iii) crop transpiration as it changes with phenology, leaf area index and growth. The system was disassembled and removed on 21 January 2008 in anticipation of harvest, which occurred on 4 February 2008.

From 2003 to 2006 equivalent measurements were undertaken in a vineyard in the Padthaway region, with one full year of measurements in each of three different vine blocks. These data were compared with those from the Riverland to determine how drivers of crop water requirements change in regions of contrasting climate, particularly across a nearly two-fold difference in mean annual precipitation from 260 mm (Riverland) to 500 mm (Padthaway) and an accompanying contrast in irrigation practices.

Riverland vineyard water use

The Riverland flux tower was located at 34.3698°S, 140.6345°E, in a drip-irrigated Chardonnay block. The vines were planted on own roots in 1996. The block was approximately 281m by 408m, or 11.5 ha in total. Vine spacing was 1.83m, row width 2.75m, and vine density 1987.1 vines/ha. The vines grew to approximately 2.2m in height. Drip spacing was 0.6m and drip application rate during irrigation was 1.24 mm/hr.

Daily sums of net ecosystem carbon exchange and crop evapotranspiration over the full measurement period from mid-February are shown in Figure 1. The coloured shading in Figure 1 delineates five seasonal periods during which growth conditions were distinctly different: (i) the end of the 2006-2007 growing season post-harvest from mid-February to mid-March when daily NEE was negative, i.e. photosynthesis outweighed respiration and there was net carbon uptake by the vines (sign convention positive upwards); (ii) the non-growing season from mid-March to late-July after the vines had stopped actively assimilating carbon and there was no undercover vegetation; (iii) the non-growing season from end-July to end-August when the grass undercover was established and assimilating carbon; (iv) the non-growing season from end-August to late-September after the undercover had been sprayed with herbicide (on 27 August) and the crop behaviour was as for period II; and (v) the 2007-2008 growing season when the vines were actively growing, irrigation was applied frequently, and net carbon uptake and evapotranspiration reached maximum values. During period I, NEE and ET were both decreasing in magnitude as the vines began to lose their leaves with the onset of autumn. During periods II and IV, NEE and ET were closely correlated and both increased after rainfall events, presumably due to the effect of increased soil moisture on soil evaporation and soil microbial activity. This soil respiration “pulse” response to rainfall has been well documented in a variety of other ecosystems including semi-arid shrubland; savanna; temperate coniferous forest; temperate mixed forest; and cool temperate deciduous forest. During period III, NEE started to diverge towards net carbon uptake as the grass undercover became established, but remained correlated with ET and rainfall events. Bud-break occurred in mid-September and during period V, NEE and ET increased rapidly through October and November to maximum seasonal values in December and January with fluctuations primarily in response to solar radiation. The negative relationship between net carbon exchange and evapotranspiration during the growing season reflects the correlation between photosynthesis and transpiration to be expected through stomatal control.

Sap flow sensors were installed in late September in five vines in the vicinity of the flux tower and four vines at a separate location, to measure vine transpiration for the 2007-2008 growing season. To scale sap flow data from individual vines to the entire block, spatial heterogeneity in the Chardonnay block was assessed with measurements of pruning weights, trunk diameters and aircraft spectral reflectance data corresponding to vegetation greenness. Scaled transpiration data (see Figure 2) showed that at the start of the growing season from late September to late October transpiration accounted for most of the crop water use. In the height of the growing season from November through January transpiration was about 60% of crop water use, implying that soil evaporation accounted for about 40% of crop water use during this period. This indicates different evapotranspiration regimes corresponding to conditions that are water-limited in the early season, and not water-limited in the later season.

Root mass density was sampled with depth and transverse distance across rows. Results indicate a strong decline in root mass density below 60 cm depth and about 60 cm transverse to the row. Soil moisture measurements at a range of depths also indicate significant drying from root activity only above 60 cm. This relatively shallow rooting depth typically results from water being applied predominantly through high-frequency drip irrigation, with little supplementary precipitation.

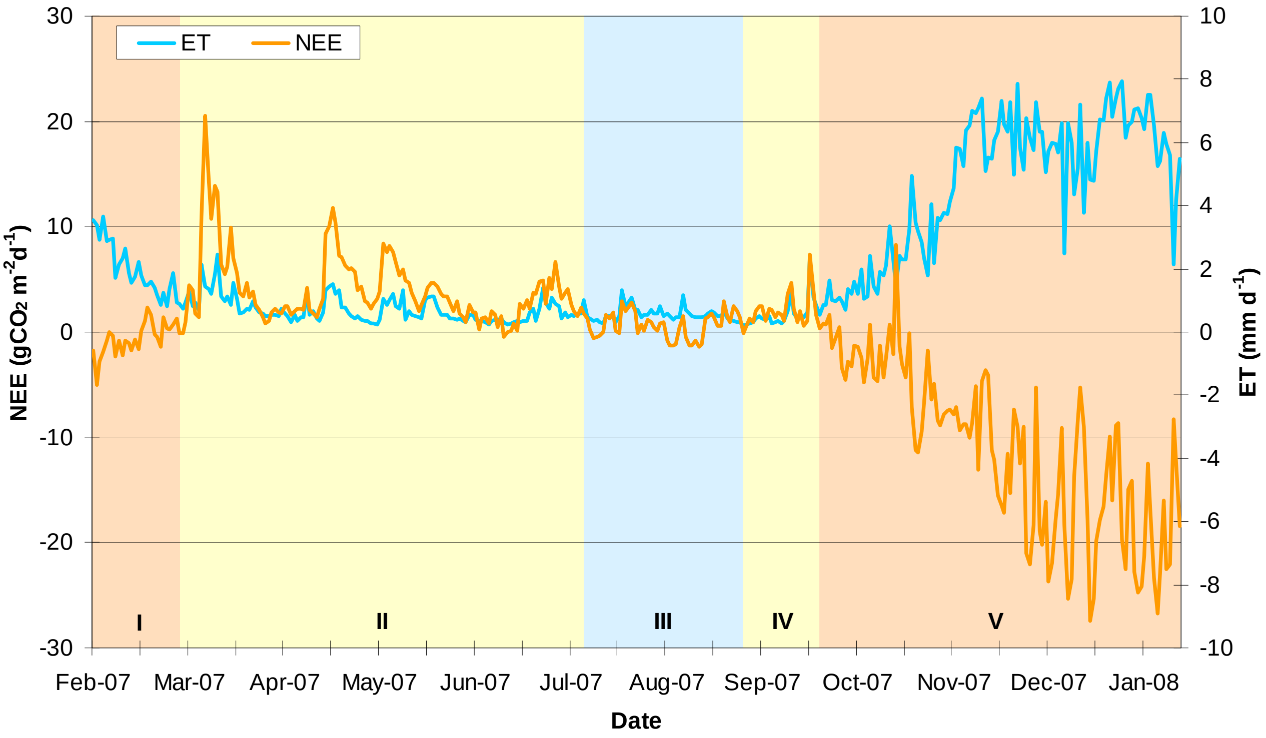

Figure 1: Seasonal time course of daily sums of net ecosystem carbon exchange NEE (orange line) and crop evapotranspiration ET (blue line). See text for explanation of coloured shading.

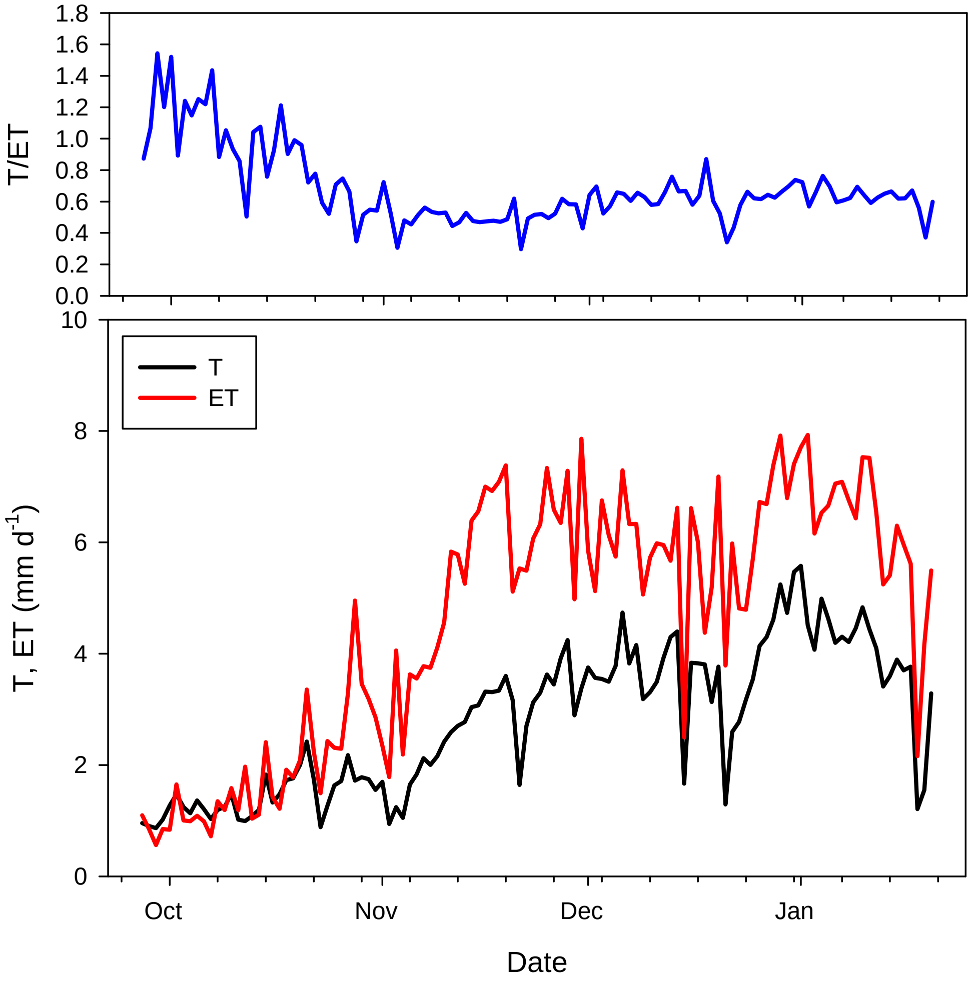

Figure 2: Top panel: ratio of daily sums of transpiration T to evapotranspiration ET. Bottom panel: daily sums of transpiration (black line) as measured by sap flow sensors and evapotranspiration (red line) as measured by eddy covariance.

Reference evapotranspiration (ET_0) was calculated according to Food and Agricultural Organisation (FAO) methodology and actual crop coefficients (K_c) determined as ET/ET_0. These were compared to tabulated crop coefficients adjusted according to soil moisture balance as recommended by the FAO (the dual crop coefficient approach), and to tabulated single crop coefficients. The comparison indicated that actual crop coefficients were greater than FAO single coefficients in the peak growing season while irrigation was applied frequently, and lower in the late growing season after harvest as irrigation frequency declined. Use of a daily soil evaporation coefficient introduced considerable variability and did not significantly improve agreement with observed K_c over the full year. Changes in soil moisture on a monthly basis correlated well with the balance between precipitation and irrigation inputs and evapotranspiration output. This suggests that there was no significant drainage at the site, although random errors and uncertainties in the data allow for a drainage loss of up to 30 mm.

Figure 3 shows monthly sums of applied water; crop water use measured with the eddy covariance instrumentation; crop water use estimated with FAO dual crop coefficients; soil water balance precipitation and irrigation inputs minus change in soil water content; and reference evapotranspiration. The figure shows that both the FAO methodology and the simple soil water balance are reasonable predictors of crop water use on the monthly scale. It also indicates that crop water use closely corresponds to applied water, as shown more clearly in the regression of Figure 4.

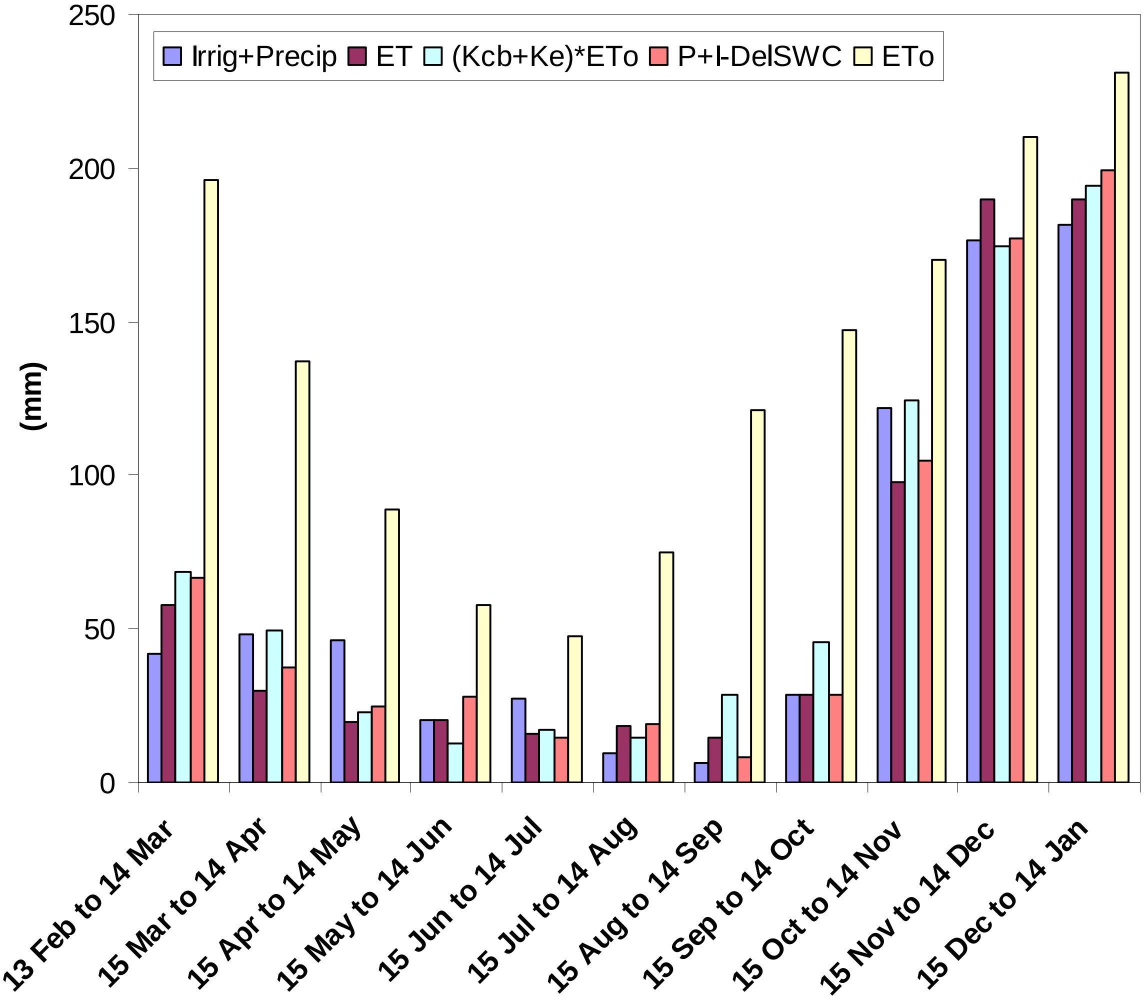

Figure 3: Monthly sums of applied water (irrigation plus precipitation); measured crop water use (evapotranspiration); crop water use estimated with crop factors and reference evapotranspiration $(K_{cb}+K_e)*ET_0$; soil water balance (precipitation plus irrigation minus change in soil water content); and reference evapotranspiration (ET_0).

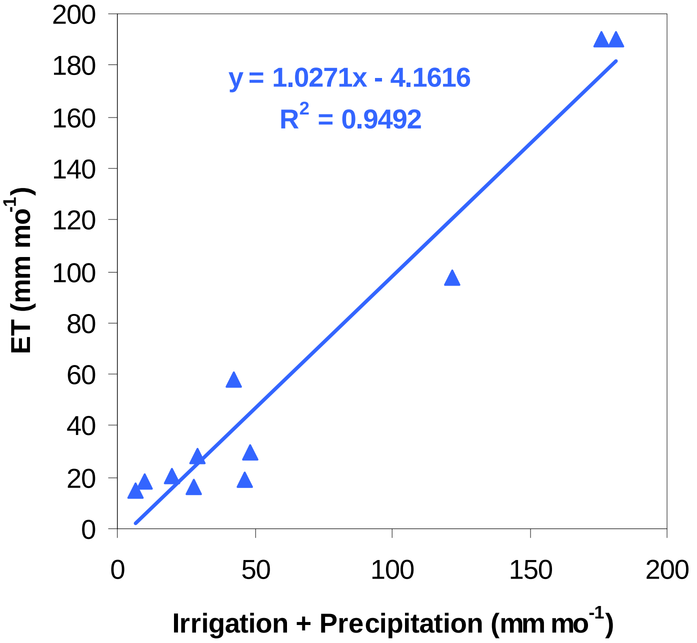

Figure 4: The response of monthly vineyard water use to irrigation and precipitation in the Riverland.

Comparison of Riverland and Padthaway vineyard water use

Vineyard water use at the Padthaway site did not reach the high values seen in the Riverland, and was more closely correlated with climate variables. This is demonstrated in Figure 5 where the Riverland evapotranspiration is highly non-linear with global radiation, in contrast to the linear response at Padthaway. This is likely a manifestation of the much higher water limitation in the Riverland, which experienced an annual rainfall of 186 mm over the measurement period, while Padthaway received 400-500 mm for each of the three measurement years. The annual total applied water (rainfall plus irrigation) was higher in the Riverland at 710 mm (up to 650 mm annually at Padthaway), but the seasonal distribution was much less constant: of the 525 mm of irrigation in the Riverland, 420 mm was applied over three months from November through January.

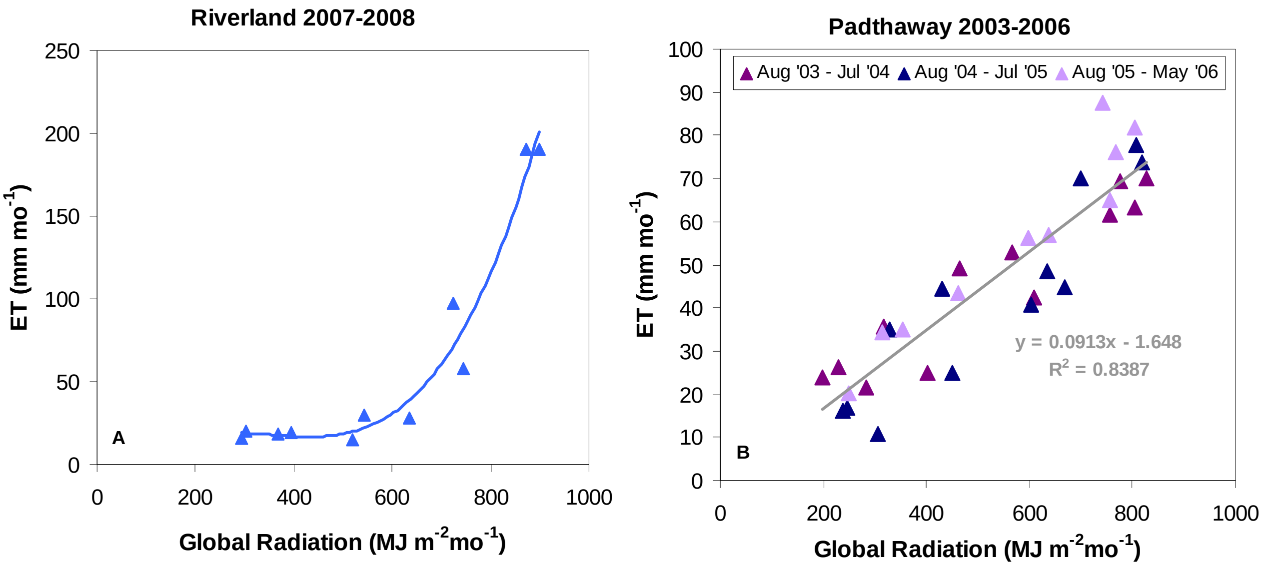

Figure 5: Monthly vineyard water use in response to global radiation in (a) the Riverland; and (b) Padthaway.

SUMMARY

Our measurements of vineyard water use in the Riverland demonstrate that crop water use is very responsive to water availability in this region. The covariance of phenology and climate variables with irrigation application complicates efforts to assess their influence; however, ET_0 is a good predictor of day-to-day variability in crop water use in response to weather-driven evaporative demand. In the less water-limited region of Padthaway, vineyard water use was less responsive to water availability and varied more predictably with climate variables. The present study provides guidance for crop behaviour in dry conditions and how water use may diverge from generic climate and phenology-driven behaviour. Soil moisture status is closely linked to crop water use and may provide guidance on variation in effective crop coefficients at the weekly timescale.