Re-examining evapotranspiration models for crop water extraction in New Zealand

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Abstract

Plant & Food Research has a number of Decision Support Systems (DSS) designed to help growers with fertiliser and irrigation management of crops (Potato Calculator, Wheat Calculator, AmaizeN Lite) as well as attempting to minimising leaching. The water extraction behind these models relies on a modified version of Penman, that was calibrated for Lincoln New Zealand on a single data set (Jamieson 1995). There is also an increasing number of tools for irrigation that is reliant on the evapotranspiration figures reported by NIWA. The NIWA calculation is based on a modified Penman reported by Burman and Pochop (1992). We implemented and examined these two models in addition to the recommended version by FAO (1998) in an attempt to determine which factors had the most effect on the predicted evapotranspiration. The models were also compared to observed water extraction data from a summer barley crop. Within the heat term the Burman Pochop model has the highest estimate of PET during the summer. During the winter months the regression form of the PFR model produces higher estimates of ET from the heat term. The aerodynamic term is significantly different between the three models producing differences of up to 60mm for a summer period with FAO model producing the higher results. There are significant differences in the winter period as well. The FAO model gave the closest result when compared to water extraction under barley during summer.

Additional keywords: Drainage, leaching, irrigation, evaporation.

Introduction

The New Zealand Institute for Plant & Food Research (PFR) has developed a number of Decision Support Systems (DSS), designed to help growers with fertiliser and irrigation management of crops (Jamieson *et al*., 2003; Jamieson *et al*., 2006; Li *et al*., 2009). These DSS are based on crop / soil models that are also used to predict drainage and leaching from agricultural land for informing policy decisions. These models were developed and tested under spring and summer conditions and have been shown to accurately reflect reality (Jamieson *et al*., 2009). An accurate water-balance model is required to schedule irrigation, and predict drainage and leaching. An accurate estimate of crop water extraction is an essential part of this. The water extraction model behind these DSS's relies on a modified version of the Penman potential evapotranspiration model (French and Legg, 1979) to calculate evapotranspiration (ET). This was calibrated for Lincoln, New Zealand on a single data set (Jamieson, 1982; Jamieson *et al*., 1995). There are also an increasing number of applications where the ET figures reported by the New Zealand Institute of Water and Atmospheric Research (NIWA) are being used to calculate drainage or to schedule irrigation. The NIWA calculation is also based on a modified Penman model (BP) as reported by (Burman and Pochop, 1994) section 4.4.10 P81. The difference between these models, other than parameters, is that the PFR model uses a regression calculation of net radiation whilst the BP model calculates net radiation from standardised equations. There is also an international standard equation for potential evapotranspiration (PET), the FAO-56 Penman-Monteith equation (Allen *et al*., 1998) that allows for crop leaf surface resistance, resulting in an equation modifying the expression containing the psychrometric constant. Thus, there are two models in use in New Zealand that have been parameterised with limited local data and the availability of an international standard that has been widely tested globally but not at a local scale, requiring verification of the many assumed values. Given the central importance of the accuracy of these models to a wide number of applications, it is important that their performance be compared over a broad range of local situations. This paper begins this process by examining the performance of these models for weather data at Lincoln, New Zealand to determine which form of the model should be used and whether any research should be conducted to test the simplifications and parameterisation of these models.

Methodology

All three models and their published parameters were implemented in C# (Visual Studio 2010). The Burman-Pochop model was validated against the Penman example by Burman and Pochop (1994). The FAO56 model was validated against example 18 (Uccle Belgium) by (Allen *et al*., 1998). The PFR model was a straight port of the model code used in the DSS.

As all the models used can be divided up into two components, the heat term (radiation-driven evaporation), and the aerodynamic term (wind- and humidity-driven evaporation). The values for these two components were examined for actual weather data, collected by an automatic weather station, at Lincoln, New Zealand.

To see how well the models performed against known water extraction the models were run against measured water extraction under barley from an experiment at Lincoln (Jamieson, 1982).

Results

In the heat term of the equations, the energy potential for evaporation comes from the net radiation values, the PFR model relying on a regression equation while the BP model uses standardised formulas.

Figure 1 shows that in summer the three models produce similar results for net radiation. However, Figure 2 shows that for the winter months the simple regression model used in the PFR PET calculations gave higher estimates of net radiation than the other two models. Figure 2 also shows that the BP model gave negative net radiation values on a number of days in winter. Figure 3 shows the total potential evaporation separated into the heat and aerodynamic components estimated by the three models for the summer period over twelve years. The BP and PFR models gave similar PET estimations (averaged over the 12 years, 428 and 413 mm, respectively) but the FAO consistently estimated approximately 25 mm less total ET. Both the BP and PFR models estimate about 30% of total PET from the aerodynamic term where as the FAO model estimated 56% of PET from the aerodynamic term. The % of PET generated from heat averaged 25% less in the FAO model than in the BP and PFR models. In the winter period (Figure 4) the estimates of total PET were similar for the PFR and FAO models (119 and 114 mm, respectively) but the BP model consistently gave 35 mm lower PET estimations. The three models differed substantially in their separation of total PET into its components, with 47%, 67% and 89% coming from the aerodynamic term for the PFR, FAO and BP models, respectively.

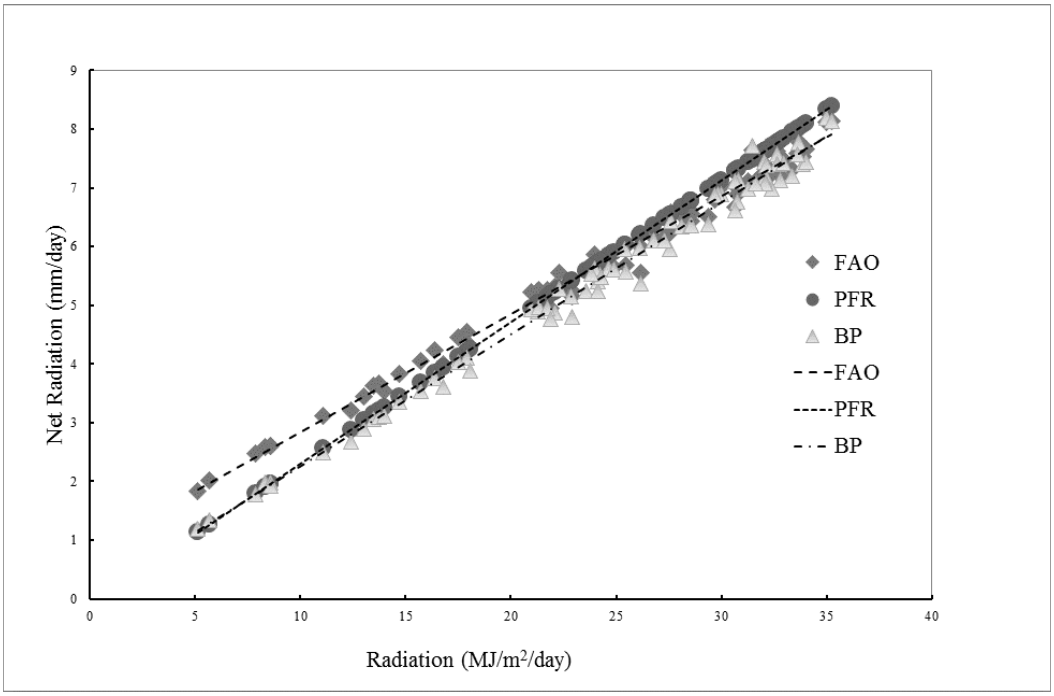

Figure 1: Calculated net radiation (mm/day) against measured radiation (MJ/m^2/day) for the summer months of December, January and February (2012-13) from the Burman Pochop (BP), Plant & Food Research (PFR) and Food and Agriculture Organisation (FAO) models at Lincoln, New Zealand.

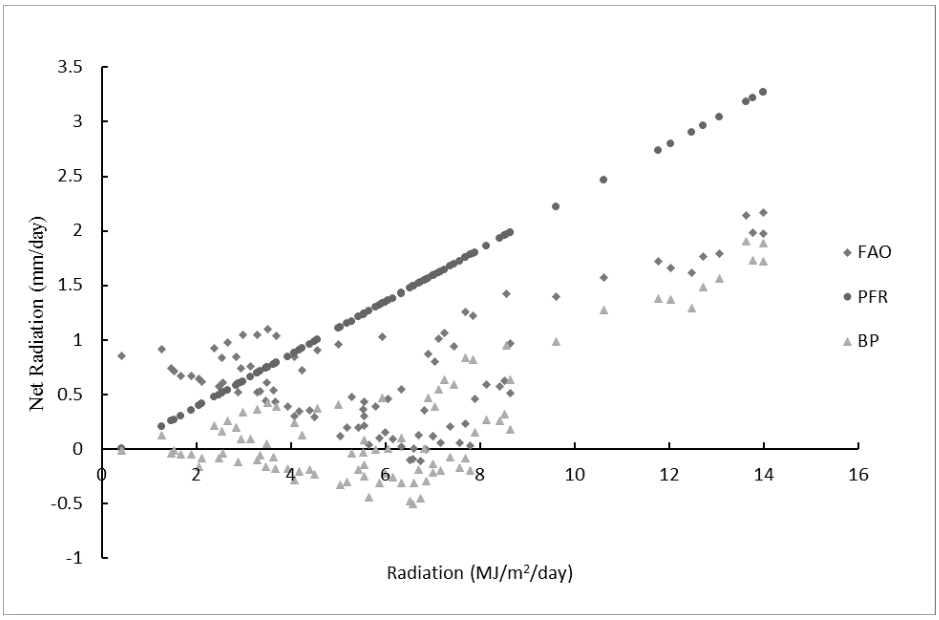

Figure 2: Calculated net radiation (mm/day) against measured radiation ($MJ/m^2/day$) for the winter months of June, July and August (2012) from the Burman Pochop (BP), Plant & Food Research (PFR) and Food and Agriculture Organisation (FAO) models at Lincoln, New Zealand.

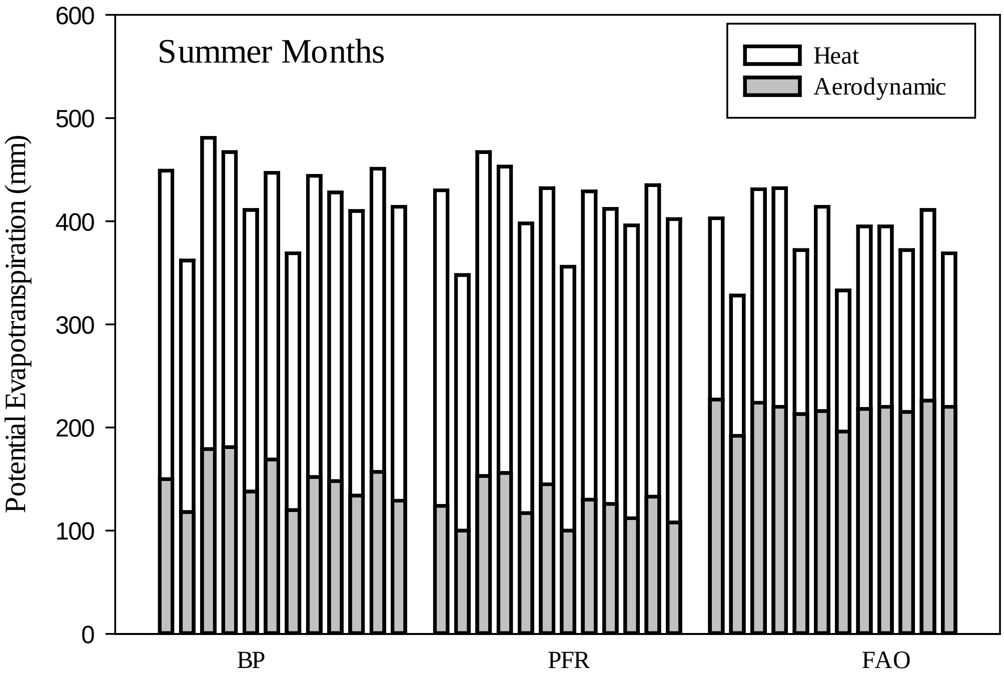

Figure 3: Total potential evapotranspiration separated into its components (aerodynamic and heat terms), estimated for the summer months of December, January and February from the Burman Pochop (BP), Plant & Food Research (PFR) and Food and Agriculture Organisation (FAO) models at Lincoln, New Zealand. Each bar is the annual summer month total potential evapotranspiration for 2000 to 2011.

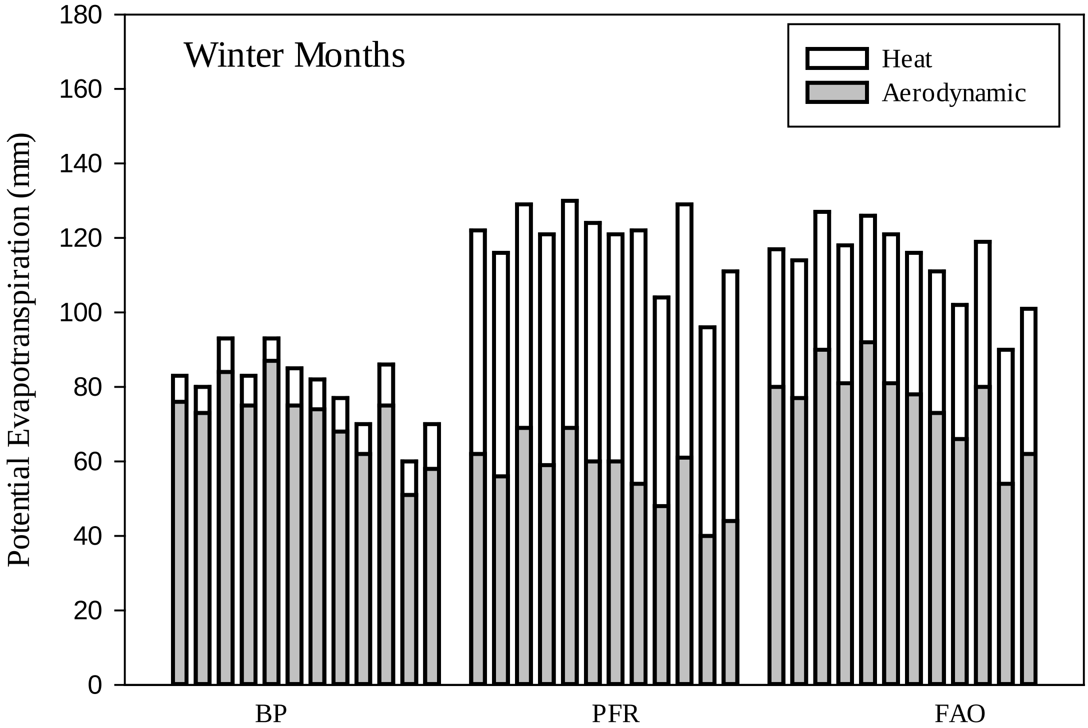

Figure 4: Total potential evaporation separated into its components (aerodynamic and heat terms), estimated for the winter months of June, July and August from the Burman Pochop (BP), Plant and Food Research (PFR) and Food and Agriculture Organisation (FAO) models at Lincoln, New Zealand. Each bar is the annual summer month total for 2000 to 2011.

Figure 5 shows the accumulated water use under a barley crop over one season (1979) measured using both neutron probe and Bowen energy ratio methods (Jamieson, 1982) compared with the accumulated PET estimated from the three models. The crop was planted in late August and water use was accumulated from early October (when the crop was nearing full cover) until the end of December (when canopy senescence began). The final value may under represent potential evapotranspiration as soil water potential in the root zone was approaching -1MPa (Jamieson, 1982). The trend in model predictions was the same as that shown in Figures 2 and 3, with the BP method giving the highest estimates and FAO the lowest. The FAO estimates were closest to those measured in the field.

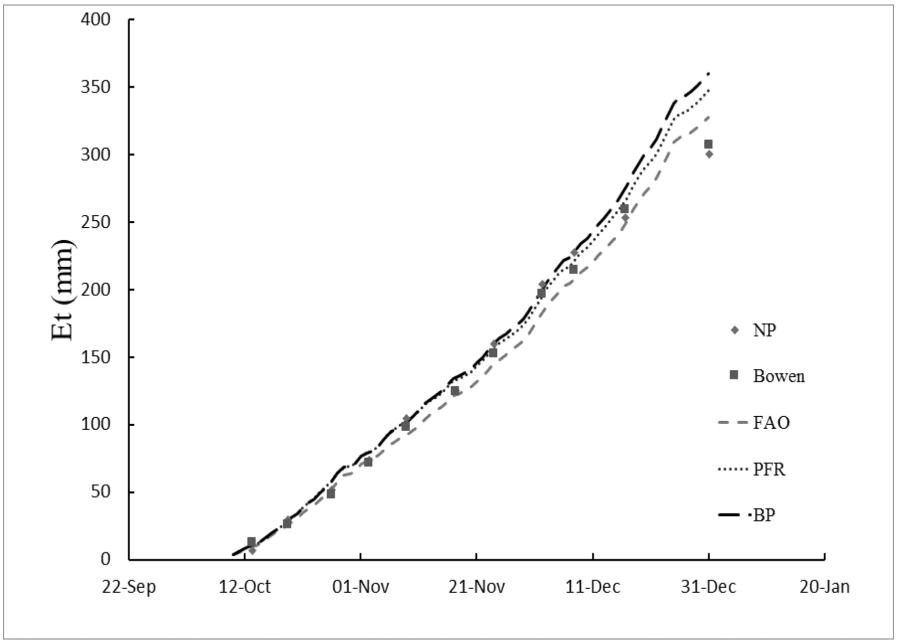

Figure 5: Estimation and measurement of cumulative water extraction (Eto) under barley in the spring / summer of 1979 at Lincoln, New Zealand.

Discussion

The use of a straight regression model for net radiation may be appropriate for a particular location and season but Figure 2 indicates that it may not be appropriate out-of-season. Thus, if the PFR model was to be used for out-of-season leaching estimates it may underestimate the amount of drainage and leachate. The BP model, with its preponderance to estimate negative net radiation during winter might underestimate winter evaporation and overestimate leaching this may occur when the net loss of radiation is positive, however further work is required to confirm this.

Including parameters to reflect leaf canopy resistance as in the FAO form of the Penman-Monteith equation does potentially make a difference of 40-50 mm over a summer season in potential evaporation, so it is definitely worthwhile to examine this effect more. This has been shown to be the case for potato crops (Kashyap and Panda, 2001).

The aerodynamic term provides a counterbalancing result to the heat term in that the FAO model has a lower potential evaporation, thus indicating that there is a possibility of compensating parameterisation.

The choice of which model to use has an impact on the predicted evaporation for a season, with the FAO model tending to predict less evaporation than the PFR and BP models. This was reflected when the case study under barley was looked at, with the FAO being closer than the PFR and BP model to measured values. If this is the case, then clearly the current practice of using the BP and PFR models for irrigation recommendations may be promoting over irrigation.

Given the uncertainly of the models, more accuracy is needed in the underlying parameters so the water uptake by crops can be modelled all year round, thus giving more confidence in the predictions for total water balance, for irrigation management and/or drainage estimates. Given also the uncertainty in historical measurements of crop water use, more accurate water balance data are required to provide robust parameterisation of PET models.

Conclusions

In conclusion, the recommendation is that further work on confirming the values of parameters for the models particularly during winter is needed. If reasonable estimates of potential evaporation during winter are required, use of a modified Penman-Monteith model like the FAO 56 model is recommended. NIWA state they are evaluating the FAO method for inclusion as another datatype, we recommend that they do so.

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