Potato Crop Water Use in Utilizing the Bowen Ratio Energy Balance (BREB) (Year1)

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1. Introduction

The quantity of soil water a plant extracts for transpiration is critical information for determining the timing of irrigation and application amount. Techniques available for determining evapotranspiration include: soil moisture monitoring (evapotranspiration as the residual in the water balance equation), weighing lysimeters, energy balance techniques, flux techniques and finally equations that estimate evapotranspiration based on meteorological inputs and plant parameters.

Weighing lysimeters are considered the most accurate by many researchers (Allen R.G. and Fisher D.K., 1991; Howell, T.A., et al., 1991) for measuring evapotranspiration at daily, hourly or even less than hourly time steps. Weighing lysimeters are expensive to construct, maintain and monitor. Additionally, weighing lysimeters are not portable so data obtained from a lysimeter at one location are not necessarily transferable to other locations.

Evapotranspiration using energy balance and flux techniques (Bowen-ratio and Eddy flux correlation respectively) have shown to agree favorably with lysimeter data in a number of studies (Malek, 1994; Yrisarry and Naveso, 2000). The Bowen-ration energy-balance technique has been widely used for determining evapotranspiration from field crops. The advantages of the Bowen ratio energy balance technique are: comparable accuracy to weighing lysimeters, portability and affordability.

The ultimate utility of determining daily evapotranspiration for various field crops is the development and refinement of crop coefficients that can be used with specific predictive equations for estimating daily evapotranspiration. Alberta Agriculture, On-Farm Irrigation Section uses the ASCE Penman-Montieth evapotranspiration equation in the Alberta Irrigation Management Model (AIMM) for estimating daily evapotranspiration from a variety of field crops. Crop coefficient curves in AIMM were not developed based on the Penman-Montieth equation and locally calibrated crop coefficient curves are needed to improve the accuracy of estimation within the AIM model and also for the products from our weather station network.

2. Theory

Incoming net solar radiation can partitioned into sensible heat exchange (creating a thermal gradient in the air), latent heat exchange (creating a humidity gradient in the air) or heating the soil (creating a soil heat flux). The complete energy balance equation to determine evaporation and/or evapotranspiration is given by:

$$ET = \frac{K + L - G - H + A_w - \dfrac{\Delta Q}{\Delta t}}{\rho_w \lambda_v}$$

where:
ET – evapotranspiration
K – net short-wave radiation
L – net long-wave radiation
G – ground heat flux
H – sensible heat exchange
A_w – water advected energy
$\frac{\Delta Q}{\Delta t}$ - change in heat storage of body per unit time
ρ_w - density of water
λ_v - latent heat of vaporization

The Bowen ratio energy balance (BREB) estimates actual evapotranspiration by calculating the partition of convective fluxes between latent and sensible heat. The ratio of sensible heat to latent heat is termed the Bowen ratio. The ratio is based on the principle of similarity and assumes the turbulent transfer coefficients for heat and water vapor are identical. The equations below list the development of the equation for determining evapotranspiration (ET). Latent heat transfer away from a crop surface can be calculated from the equation:

$$\rho_w \lambda_v ET = \frac{0.622 \rho_a (v_{a2} - v_{a1})(e_{v2} - e_{v1})}{P \rho w 6.25 \left[\ln \left(\frac{z_{m2} - z_d}{z_{m1} - z_d} \right) \right]^2}$$

Equally, sensible heat transfer away from a crop surface can be calculated by the equation:

$$H = \frac{c_a \rho_a (v_{a2} - v_{a1})(T_{a2} - T_{a1})}{6.25 \left[\ln \left(\frac{z_{m2} - z_d}{z_{m1} - z_d} \right) \right]^2}$$

Incorporating the Bowen ratio technique or the ratio of sensible to latent heat, the need for wind data (v_a), crop aerodynamic resistant data (z_m and z_d) and air density (ρ_a) are eliminated. The requirement for the Bowen ratio method is that both the temperature (T) and vapor pressure gradients (e) are measured at two heights above the crop canopy

$$\beta = \frac{H}{\rho_w \lambda_v ET} = \frac{c_a P (T_{a2} - T_{a1})}{0.622 \lambda_v (e_{v2} - e_{v1})}$$

Rearranging the energy balance equation to incorporate the Bowen ratio

$$K + L - G - \rho_w \lambda_v ET - H = 0$$

yields:

$$ET = \frac{K + L - G}{\rho_w \lambda_v (1 + \beta)}$$

3. Methods and Materials

The Campbell Scientific Bowen Ratio apparatus includes instrumentation to measure all of the parameters necessary to solve the final energy balance equation. The Bowen ratio system description is included in Appendix A.

The BREB apparatus was erected in the potato field at the CACDI Lethbridge Demonstration Farm on June 21-22, 2004 (Figure 1). Installation and setup followed the Campbell Scientific Bowen ratio instrumentation instruction manual (Campbell Scientific, 1998). The CR23X datalogger was programmed to output the measurements from all the sensors to final storage every 20 minutes.

Figure 1. Initial installation of BREB system.

The accuracy of the Bowen ratio values was done using the procedure suggested by Perez et al., 1999.

4. Results and Discussion

Erroneous Bowen ratio values were calculated from the early data that was obtained from the system. Comparisons were made to other independent data obtained from others using the Bowen ratio system and it was determined that differences with the vapor pressure between the upper and lower arm were insufficient to obtain reasonable Bowen ratio values. Troubleshooting the problem began with the Bowen ratio program, extended to the wiring of the cooled mirror hygrometer and finally was identified as a wiring problem with the vacuum pump control. Once the wiring was corrected, reasonable daily ET values were obtained.

Comparisons were made to the ASCE Penman Monteith (ASCE PM) model and to the current routine for estimating potato ET within the Alberta Irrigation Management Model (AIMM) (Table 1).

Table 1. Comparisons of daily ET values (mm) from the various predictive equations.

	Bowen	ASCE PM alfalfa reference	ASCE PM grass reference	AIMM	Irrigation	Rainfall
19-Aug	4.6	4.1	2.5	4.5	0	6.9
20-Aug	5.9	4.1	2.5	4.6	20.5	0.2
21-Aug	3.8	3.7	2.3	4.7	0	1.5
22-Aug	3.1	2.4	1.5	4.6	20.5	0.8
23-Aug	0.0	0.9	0.7	4.5	0	6.3
24-Aug	4.5	3.3	2.0	5.0	0	0
25-Aug	1.0	1.0	0.7	2.9	20.5	4.1
26-Aug	3.0	1.7	1.1	3.8	0	5.9
27-Aug	5.3	4.4	2.7	5.9	0	0
28-Aug	3.0	4.2	2.6	5.2	0	1.2
29-Aug	5.1	3.6	2.2	4.9	0	0
30-Aug	5.6	4.9	2.9	5.5	0	0
31-Aug	4.7	5.3	3.2	4.7	0	0
1-Sep	3.2	2.9	1.9	3.3	0	2
2-Sep	3.8	5.8	3.5	5.8	0	0
3-Sep	2.8	3.5	2.2	3.9	0	0
4-Sep	4.7	5.3	3.2	5.7	0	0
5-Sep	3.6	3.7	2.3	3.7	0	1
6-Sep	4.0	2.5	1.6	3.2	0	0.2
7-Sep	1.3	1.2	0.9	2.2	0	0.5
Totals (mm)	73.0	68.5	42.7	88.4	61.5	30.6

It is apparent from the limited data that the crop coefficient curve within the AIM model overestimates evapotranspiration for potatoes. A full growing cycle with a fully operation Bowen ratio system collecting reasonably accurate ET numbers will confirm these early findings and adjustments to the crop coefficient curves can proceed with confidence.

5. Conclusions

Comparative ET numbers were obtained once the initial problems with the low difference in vapor pressure between upper and lower arms were resolved. The instrumentation will prove invaluable to improve the accuracy of ET prediction for the various products offered through the Irrigation Branch.

6. References

Allen, R.G. and Fisher, D.K. 1991. Direct load cell-based weighing lysimeter system. In: Proc. of 1991 ASCE specialty conference on "Lysimeters for evapotranspiration and environmental measurements", Honolulu, Hawaii, 1991. 444 pages.

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Appendix A

Bowen Ratio System

System Description: This system will measure evapotranspiration using the energy balance Bowen ratio technique. This is accomplished through the automated measurement of water vapour gradients, air temperature gradients, soil heat flux and net radiation.

System requirements: The system shall consist of the following components:
- Data collection platform
  - datalogger
  - additional data storage
- Water vapour analyzer
- Air temperature gradient measurement
  - fine-wire thermocouples
- Net radiation measurement
- Soil heat flux measurement
  - heat flux transducer
  - soil temperature sensors
  - soil moisture measurement
- Power system
  - separate power supplies for datalogger and sensor array
- Tripod, mounting hardware and necessary wiring for all specified equipment

Specifications:
Data Collection Platform
Datalogger (**1 unit** required)
- Campbell Scientific CR23X (or equivalent)
- Memory: Minimum 4 Megabyte RAM (Flash)
- Operating Range: -40° to +50° C
- On-board display: LCD
- Analog Inputs: 12 differential or 24 single ended (15-bit resolution, selectable voltage range)
- Pulse counting channels: Four 8-bit (or two 16-bit) pulse channels (switch closure, low-level ac pulses, high frequency pulses)
- Excitation channels: Four outputs, programmable throughout ± 5V range
- Power connections: Switched 12V power terminal, continuous 12 V and 5V terminals.

Data Storage Module: ***32 Mbytes*** total additional storage required
- 2 - Campbell Scientific SM16M –55 (or equivalent)
- Portable data storage devices, to be used to augment datalogger storage. Memory: 16 Megabytes (Flash) EEPROM

- Extended Operating range: -55° to +65° C
- Connection: 9-pin cable to interface with datalogger or PC

Water Vapour Measurement System

Vapour Analyzer (**1 unit** required)

- Bowen Ratio flow controller
- Modified for use with HMP45C sensor for vapour measurement
- Enclosure included (internal dimensions: 16.0"W x 18.0"H x 9.0"D)
- Includes 10 extra air intake filters

Relative Humidity / Temperature Probe (**1 unit** required)

- Campbell Scientific HMP45C RH/Temp probe (or equivalent)
- 0-100% relative humidity measurement range
- -40° to + 60° C temperature measurement range
- Integral power switching circuit (12 V)

Upper and Lower Sensor Arms (**2 units** required [1 upper arm + 1 lower arm])

- Sensor mounting hardware for vapour intake and air temperature
- Each arm shall include: air intake, filter, thermocouple connector, thermocouple wire, and air intake tubing

Air Temperature Gradient Measurement

Fine-wire thermocouple (**4 units** required [includes 2 spare units])

- Type E fine wire thermocouple (0.003" diameter)

Aspirated Thermocouple (**2 units** required)

- Type E fine wire thermocouple (0.003" diameter)
- Includes aspirated radiation shield
- 12 Vdc fan, intake velocity: 5.5 m/sec

Net Radiation Measurement

Net Radiometer (**1 unit** required)

- Kipp & Zonen NR Lite Net Radiometer(or equivalent)
- Measurement range: ±2000 W/m^2
- Operating range: -25° to + 70° C
- Includes mounting bracket

Soil Heat Flux Measurement

Heat Flux Transducer (**2 units** required)

- Campbell Scientific HFT3 (or equivalent)
- Thermopile sensor (plate design)
- Measurement range: ± 100 W/m^2
- Includes wire for connection to datalogger

Averaging Soil Temperature Probe (**1 unit** required)

- Type E thermocouple probe
- 2 x 2 thermocouple configuration (4 junctions total)
- Includes wire to connect to datalogger

Water Content Reflectometer (**1 unit** required)

- Campbell Scientific CS616 (or equivalent)
- Time-domain reflectometry method
- Capable of measurements over a 30 cm depth
- Compatible with specified datalogger

Power Supply

Datalogger power:

- 12 V sealed rechargeable lead-acid battery (or 2 @ 6V)
- 7 Ahr rating
- 12 Volt battery charger w/ voltage regulator
- 10 Watt solar panel w/ mount and 3 m wire leads
- enclosure for battery and regulator

Sensor power:

- 30 Watt solar panel, w/ 12 volt regulator, w/mounting hardware, w/ 3 m wire leads
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Mounting Hardware

Tripod (**1 unit** required)

- Portable 10 ft. instrument tower
- Individually adjustable legs
- Lightning rod w/ clamps and conductor
- Grounding kit w/ hardware

Additional Hardware

- Peripheral to RS232 interface cable (to connect computer to datalogger)