ARTICLE IN PRESS

Available online at www.sciencedirect.com

SCIENCE DIRECT®

Agricultural and Forest Meteorology xxx (2004) xxx–xxx

AGRICULTURAL AND FOREST METEOROLOGY

www.elsevier.com/locate/agrformet

Correspondence

Comment on “Measurement and modeling of growing-season canopy water fluxes in a mature mixed deciduous forest stand, southern Ontario, Canada”

Richard F. Keim*

School of Renewable Natural Resources, Louisiana State University, Baton Rouge, LA 70803, USA

Received 16 October 2003

Price and Carlyle-Moses (2003) (hereafter PCM) quantified the water balance of precipitation on a forest canopy by measuring rainfall, throughfall, and stemflow. In using the data to calibrate the Gash model of evaporative loss (Gash, 1979; Gash et al., 1995; Valente et al., 1997), PCM improved predictions by varying the storage capacity parameter, S_c, conditional on rainfall intensity. PCM concluded that this improvement is evidence that supports the hypothesis of Calder (1986, 1996) that “the storage capacity of a stand is reduced when rain-drops and thus, rainfall intensities are large.”

In this comment, I show that this conclusion is not warranted by the data presented in the paper, and that there is evidence that storage in the canopy may have been actually higher during events of greater intensity.

By splitting their data into storms of high and low mean intensity, PCM also split the data into storms of short and long duration (t-test; $P = 0.05$), and more and less rain amount (t-test; $P = 0.11$) (Fig. 1). Therefore, it is clear that differences in interception between the two groups cannot be attributed solely to intensity, and PCM have no basis to form any conclusions about simple effects of rainfall intensity.

Ever since Horton’s (1919) pioneering work, canopy interception scientists have understood that *duration* of rainfall is most related to storm-total evaporation, but the most readily available data is normally the *total amount* of rainfall. This is partly why Gash’s model is so useful in application, and why work such as presented by PCM is important. Because rainfall intensity is the ratio of amount to duration, examining the relationship between intensity and canopy interception processes is only meaningful when the analysis controls for duration. Complicating matters is that longer-duration storms normally have lower average intensity.

1. Re-analysis, controlling for event duration

Comparing storms of equivalent durations but different intensities in PCM’s data reveals greater evaporation in high-intensity storms (Fig. 2). Three common assumptions allow use of this relationship to estimate differences in canopy storage among storms: (1) total evaporation is the sum of evaporation during the storm and storage at the end of the storm (Horton, 1919); (2) the rate of evaporation was the same during all storms in PCM’s experiment (Gash, 1979); and (3) the canopy was fully wet during all storms in PCM’s experiment, so that storage did not limit evaporation. Given two

* Tel.: +1-225-578-4169; fax: +1-225-578-4227.
E-mail address: rkeim@lsu.edu (R.F. Keim).

doi:10.1016/j.agrformet.2004.02.003

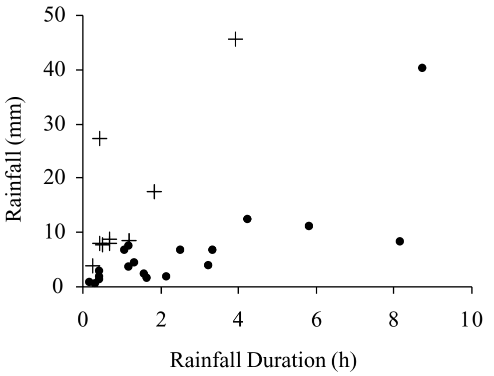

Fig. 1. Total rainfall in storms of different durations in a hardwood forest in Ontario. Dots indicate storms with mean intensity $<7\,mm\,h^{-1}$ and crosses indicate storms with mean intensity $>7\,mm\,h^{-1}$. Data are from Price and Carlyle-Moses (2003) (Table 3).

storms of equal duration, then, these assumptions dictate that the storm with the greatest total evaporation must have had the greatest storage at the end.

This logic dictates that the high-intensity storms measured by PCM would have had more water stored on the canopy. Systematic violations of assumptions (2) and (3) would invalidate this conclusion, however. For example, the assumption of equal evaporation rates among storms may been violated because the high-intensity storms in PCM's experiment tended to occur during the middle of the summer when temperatures were presumably higher. More information would be required to draw a strong conclusion about the actual canopy storage.

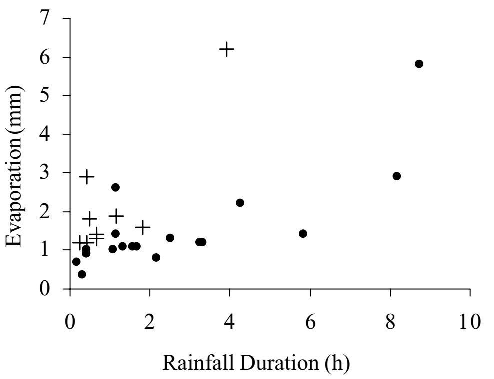

Fig. 2. Total evaporation (rainfall–throughfall–stemflow) during storms of different durations in a hardwood forest in Ontario. Dots indicate storms with mean intensity $<7\,mm\,h^{-1}$ and crosses indicate storms with mean intensity $>7\,mm\,h^{-1}$. Data are from Price and Carlyle-Moses (2003) (Tables 3 and 5).

2. Measured and modeled canopy storage in the literature

Calder's (1986) hypothesis that canopy storage decreases with rainfall intensity enjoys widespread acceptance. However, published data have refuted the concept. Field measurements of canopy storage during rainfall have generally shown storage increases during periods of higher rainfall intensity (e.g., Calder and Wright, 1986; Klaassen et al., 1998). In the laboratory, Aston (1979) found storage on branches was higher at simulated rainfall of higher intensity. Finally, Hall (2003) has shown recently that predictions of evaporation by the model of Calder's (1986) are insensitive to assumptions about intensity-dependent storage, and the superior performance of that model is mainly the result of an improved representation of canopy wetting.

The simplifying assumptions of the Gash model are assets for estimating evaporation, but are not conducive to detailed physical interpretation of model parameters or results. Klaassen (2001) recently highlighted this fact, and suggested that the usefulness of even the full Penman–Monteith equation (e.g., by Rutter et al., 1971) depends on compensating errors. Examples of this problem can crop up in measurements of fluxes and stores that are normally only estimated in application (e.g., Calder and Wright, 1986). Specifically, Vrugt et al. (2003) found that measurements of throughfall are inadequate for identifying canopy storage and evaporation during rainfall. Thus, physical interpretation of parameters estimated by statistical calibration of the Gash model is risky, and the conclusion by PCM that intensity reduces storage cannot be accepted without supporting data.

3. Conclusions

One of the main conclusions by Price and Carlyle-Moses (2003) was that canopy storage decreased during rainfall of high-intensity in their field study. However, this conclusion is based on the faulty reasoning that correlation between meteorological conditions and optimized model parameters is sufficient evidence of physical phenomena. This commentary has shown that their conclusion is not supported by the data they presented, and that those data more strongly support the conclusion that canopy storage was actually greater during storms of higher intensity.

References

Aston, A.R., 1979. Rainfall interception by eight small trees. J. Hydrol. 42, 383–396.

Calder, I.R., 1986. A stochastic model of rainfall interception. J. Hydrol. 89, 65–71.

Calder, I.R., 1996. Dependence of rainfall interception on drop size. I. Development of the two-layer stochastic model. J. Hydrol. 185, 363–378.

Calder, I.R., Wright, I.R., 1986. Gamma ray attenuation studies of interception from Sitka spruce: some evidence for an additional transport mechanism. Water Resour. Res. 22, 409–417.

Gash, J.H.C., 1979. An analytical model of rainfall interception by forests. Q. J. R. Meteorol. Soc. 105, 43–45.

Gash, J.H.C., Lloyd, C.R., Lachaud, G., 1995. Estimating sparse forest rainfall interception with an analytical model. J. Hydrol. 170, 79–86.

Hall, R.L., 2003. Interception loss as a function of rainfall and forest types: stochastic modelling for tropical canopies revisited. J. Hydrol. 280, 1–12.

Horton, R.E., 1919. Rainfall interception. Mon. Weather Rev. 47, 603–623.

Klaassen, W., Bosveld, F., de Water, E., 1998. Water storage and evaporation as constituents of rainfall interception. J. Hydrol. 212–213, 36–50.

Klaassen, W., 2001. Evaporation from rain-wetted forest in relation to canopy wetness, canopy cover, and net radiation. Water Resour. Res. 37, 3227–3236.

Price, A.G., Carlyle-Moses, D.E., 2003. Measurement and modelling of growing-season canopy water fluxes in a mature mixed deciduous forest stand, southern Ontario, Canada. Agric. For. Meteorol. 119, 69–85.

Rutter, A.J., Kershaw, K.A., Robins, P.C., Morton, A.J., 1971. A predictive model of rainfall interception in forests, 1. Derivation of the model from observations in a plantation of Corsican pine. Agric. Meteorol. 9, 367–384.

Valente, F., David, J.S., Gash, J.H.C., 1997. Modelling interception loss for two sparse eucalypt and pine forests in central Portugal using reformulated Rutter and Gash analytical models. J. Hydrol. 190, 141–162.

Vrugt, J.A., Dekker, S.C., Bouten, W., 2003. Identification of rainfall interception model parameters from measurements of throughfall and forest canopy storage. Water Resour. Res. 39, 1251 (doi:10.1029/2003WR002013).