

EVAPORATION AND TRANSPIRATION

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For years, the principal objective of evapotranspiration research has been to calculate the loss of water under varying conditions of climate, soil, and vegetation. The early simple empirical methods have generally been replaced by more detailed models which more closely represent the physical and biological processes involved. Monteith's modification of the original Penman

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evapotranspiration equation to include a term for canopy resistance signaled a shift in emphasis in evapotranspiration research from a physically controlled process to one which can be physiologically controlled. This change in direction was acknowledged by Federer [1975] in his earlier review and has continued for the past four years. The scope of this review, as were the reviews of Ekern [1971] and Federer [1975], is, for the most part, limited to evaporation from terrestrial surfaces rather than from lake or ocean surfaces.

A review of the literature since 1974 shows that substantial interest has been maintained in understanding the influence of advection and interception on evapotranspiration. As the complexity of the models increases, the data requirements to drive the equations often make the model useless for field applications. Consequently, there is a continual effort to make empirical substitutes to satisfy local conditions. Under a number of circumstances, such modifications work very well. For example, from the Penman-Monteith equation, if the canopy resistance and aerodynamic resistance are of the same magnitude - as for short crops in temperate climates - then evapotranspiration will be fairly insensitive to canopy resistance and an empirical adjustment to the formula will be adequate. If the aerodynamic resistance is much less than the canopy resistance - as it is in forests - the calculated evapotranspiration is greatly affected by the value of the canopy resistances [Rutter, 1975; Tan and Black, 1976].

Canopy Resistance

Canopy resistance is the result of the interaction of the soil-plant-atmosphere system, no one part of which operates independently of the other. The internal water relations within a plant tend toward a steady state in which water uptake, translocation, and transpiration are equal. When evaporative demand exceeds the ability of the roots to supply the necessary water, some species can draw upon water stored within the plant or close their stomata. A prime function of stomata is to prevent leaf desiccation after soil water extraction by the plant has fallen behind the rate of water loss.

The simple Penman-Monteith model assumes that the canopy is isothermal and that the canopy resistance is equal to all of the stomatal resistances acting in parallel. However, canopy resistance has been shown to be largely of a physiological origin and can vary substantially within a plant [Tan and Black, 1976; Sinclair et al., 1976]. The nature of canopy resistance has been found to differ not only between different species, but also between different genetic strains of the same species [Shimshi and Ephrat, 1975; Hall et al., 1976; Jones, 1976] and the stage of crop development [Nkemdirim, 1976]. Some plants have less ability to control water loss than others. For example, Johns [1978] found that stomata closure in a number of temperate herbage species was able to reduce water use by only 20 to 30% and that water use continued at a high rate even when water stress was causing considerable leaf death.

The canopy resistance term found in Monteith's model was expanded by Rijtema and later by Feddes to include terms for stomatal resistance, resistance dependent of the availability of soil moisture and on liquid flow in the plant, and resistance dependent on the degree of soil cover. Although these terms are certainly not independent, the Rijtema-type model has been found to evaluate successfully the surface factors that control evapotranspiration and to be a substantial improvement upon the Penman-Monteith estimate [Grant, 1975; Nkemdirim, 1976; Thom and Oliver, 1977].

Stomata

The role of stomata in the regulation of transpiration has been widely studied. The environmental factors that have a major influence on stomatal resistance are irradiance [Hall et al., 1976], leaf water status [Jarvis, 1976; Shirazi et al., 1976a, b; Denmead and Millar, 1976; West and Gaff, 1976], humidity [Raschke, 1975; Idle, 1977; Rawson et al., 1977; Sheriff, 1977a], leaf temperature [Hall and Kaufmann, 1975; Aston, 1976; Ford et al., 1977], and carbon dioxide concentration [Raschke, 1975; Hall et al., 1976]. Studies of stomatal response to these environmental factors have often yielded contradictory results. Some of these contradictions may be related to methodology, whereby the result is affected by the process of measurement. For example, damaging a *Lycopersicon* leaf caused a 41% average reduction in transpiration in a neighboring undamaged leaf which persisted for several hours. Such artifacts can influence transpiration from an excised leaf or the entire shoot if endogenous hormones released from the damaged cells gain entry to the transpiration stream [Van Sambeek and Pickard, 1976]. Instrumentation, such as porometers, which do not adequately maintain CO₂ and humidity gradients may cause changes in stomatal aperture which are independent of the variable being studied. Hall et al. [1976] suggest that porometer systems which maintain the ambient humidity at the leaf surface during measurement are perhaps necessary --even for short measurement periods. Greater care in plant preconditioning must be exercised.

Time-dependent effects of environmental stresses on stomatal responses is an important consideration. Stomata of plant material suddenly exposed to water stress do not respond similarly to those of plant material growing in a field situation where stresses are slowly and continually changing and tissue-solute concentrations are allowed to adjust over relatively long periods [Begg and Turner, 1976; Brown et al., 1976; Johns, 1978]. After-effects of water stress on subsequent stomatal responses also have been observed [Hall et al., 1976]. The age of the leaf or its position in the canopy is an additional source of variation which must be considered when evaluating stomatal resistances in a plant [Hsiao et al., 1976; Aslam et al., 1977; Rawson et al., 1977].

Soil Moisture Availability and Plant Conductance

The effect of soil drying on the transpiration rate requires consideration of the simultaneous interaction of the atmospheric demand, the water potential of the leaf, the resistance to water movement in the plant, and the soil water potential. For years there have been conflicting views about the manner in which transpiration rate responds to the drying of soil. There is increasing evidence that the form of this relationship can be explained in terms of varying climate, plant, and soil factors [Rutter, 1975; Sterne et al., 1977; Calder, 1978]. Afshar and Marino [1978] propose a model that considers potential transpiration and effective root density. Their model does not account for the ability of the plant to control water uptake when soil water is limiting, however. Root density functions are often taken as a function of root biomass, and such data are often dif-

ficult to obtain. The development of root systems can be quite dynamic and vary with species, season, and depth [Hsiao et al., 1976].

The task of evaluating root densities of forest vegetation is a major undertaking. Ziemer [1978] found soil moisture was actively depleted by forest trees to a depth in excess of 7 m. Maximum soil moisture extraction by the roots occurred between a depth of 3 to 5 m. Feddes et al. [1976] proposed a root extraction term which depends on potential evapotranspiration, soil moisture content, and the depth of the root zone. A modification of their model, in which the soil moisture term is replaced by one related to the soil moisture pressure head, produced results which agreed with data collected in a field planted with red cabbage [Feddes and Zaradny, 1978]. Although progress has been made in understanding the interaction of transpiration and drying soils, the ability to apply these principles to field situations continues to be limited because of the difficulty of acquiring the necessary data [Rutter, 1975; Seaton et al., 1977; Lauenroth and Sims, 1976; Calder, 1976; Jensen and Wright, 1978]. To avoid the data acquisition problems related to direct measurements of soil water availability, predawn xylem pressure potential has been found to be a useful substitute [Ritchie and Hinckley, 1975; Fetcher, 1976]. Other studies have related xylem water potential to transpiration rate [Landsberg et al., 1976].

Aerodynamic Resistance

Rijtema suggested that the aerodynamic resistance in the Penman-Monteith equation could be related to the inverse of a roughness function. He defined the function as the product of crop height and a dimensionless function of windspeed. Although the relationship was originally established for grass in the Netherlands, the addition of the roughness function produced a marked improvement over the original Penman equation for calculating evapotranspiration by a number of crops in arid and semi-arid regions [Slabbers, 1977]. Nkemdirim [1976] found a progressive increase in the roughness parameter as a potato crop developed. The roughness parameter was highly correlated with crop height and spread. Roughness length is also influenced by crop flexibility. As wind velocity increases, a flexible canopy may irregularly deform which increases the roughness length and, therefore, evapotranspiration relative to a rigid canopy [Heilman and Kanemasu, 1976]. With increasing height of the vegetation there is a corresponding increase in the roughness length and, for a given windspeed, a decrease in the aerodynamic resistance. When the roughness length becomes very large, as in a forest, the calculated evapotranspiration can substantially exceed open water evaporation [Thom and Oliver, 1977]. A diurnal variation in aerodynamic resistance was noted by Nkemdirim [1976] in his potato crop study with variations up to 48% in hourly values in early spring. Later in summer, such variability was usually less than 10%. High values were found to correspond to periods of active convection. In addition, spring weather was much more unsettled than was the more stable summer weather.

The calculation of evapotranspiration of intercepted precipitation is a special application of the Penman-Monteith equation. In this application, canopy resistance is negligible when the canopy is completely wet [Shuttleworth, 1975], but increases slowly as a larger portion of it dries [Gash and Stewart, 1975]. Rutter et al. [1975] developed a physically based model for forests which calculates a running water balance of the canopy and trunks using hourly rainfall and the necessary meteorological data to use the Penman-Monteith equation. Their model was tested against records from a wide range of forest canopies and was able to account for differences in measured interception loss between species and between leafy and leafless deciduous stands. Rutter [1975] reasoned that in herbaceous communities, where the aerodynamic and canopy resistances are approximately equal, the evapotranspiration rate of intercepted water will be about equal to the potential evapotranspiration rate. However, in forests where the dry canopy resistance greatly exceeds the aerodynamic resistance, the rate of evaporation of intercepted water might be 3 to 5 times the rate of potential evapotranspiration. Predictions based on the model have been verified through subsequent studies by Calder [1978], Gash and Stewart [1977], and Stewart [1977].

Rutter [1975] states that the temperature of a wet canopy is often lower than that of the surrounding air and that the small aerodynamic resistance found in forests allows a rapid sensible heat flux to move down such a temperature gradient into the canopy. This same principle was demonstrated in a model developed by Murphy and Knoerr [1975], who concluded that such enhanced evaporation can occur for forests of large areal extent, where horizontal advection may be small. This point was questioned by McNaughton [1976], who concluded that without the contribution of advected energy there would be no increase in the evaporation rate of intercepted water when the canopy is wet. Rutter [1975] observed that the rate of interception loss in the winter in coniferous forests may be as rapid as that in summer. He explained that this is possible because (1) the energy for evaporation of intercepted water comes mainly from the air, as previously discussed, rather than net radiation; (2) that temperature and saturation deficits differ much less between summer and winter on rainy days than on dry days, at least in England; and (3) that windspeeds tend to be higher in winter and thus aerodynamic resistance is lower. Calder [1977] found that reliable predictions from the Rutter-type interception model were very sensitive to small errors in the measurement of vapor pressure deficit. He concluded that without improvements in the measurement of such meteorological variables, there is little to be gained in further development of transpiration and interception models.

Advection

The influence of the advection of sensible heat from a relatively dry area to a more moist area is a problem which has long plagued attempts to evaluate evapotranspiration. In such cases, the

energy used for evapotranspiration by well-watered crops can exceed the energy supplied by net radiation by a factor of 2 [Verma et al., 1978]. When this difference occurs, the saturation pressure deficit term in the numerator of the Penman-Monteith equation becomes relatively more important [Rutter, 1975; Jury and Tanner, 1975]. This relationship reiterates the importance of accurately measuring vapor pressure deficit in the field, as discussed by Calder [1977]. The Bowen ratio-energy balance method has been widely used as an indication of the performance of other models, including the Penman-Monteith equation. The Bowen ratio technique has been found to be reasonably accurate under non-advective conditions. However, under advective conditions, Verma et al. [1978] found that the Bowen ratio consistently underestimates evapotranspiration from well-watered alfalfa growing in a lysimeter by 20 to 30%. This underestimation was in response to advection of a regional scale, not from local influences due to insufficient fetch. The Bowen ratio approach assumes that the exchange coefficient for sensible heat is equal the exchange coefficient for water vapor. During advective conditions, the transfer of heat and water vapor is often in opposite directions [Verma et al., 1978]. Warhaft [1976] has shown theoretically that under such situations large differences in the two exchange coefficients will occur. Morton [1975, 1976, 1978] has proposed a complementary relationship between potential evapotranspiration estimated at a climatological station and the evapotranspiration from the surrounding area. In other words, the potential evapotranspiration is viewed as both the cause of areal evapotranspiration and the effect of areal evapotranspiration. This view is consistent with that of the relative importance of regional advection discussed above. Thus, rather than this being an iconoclastic view, as suggested by Morton, it is one further example of the importance that evapotranspiration models adequately evaluate the influence of regional as well as local advection.

Soil Water Evaporation

Evaporation of water from the soil is controlled by the availability of energy and the rate of water conduction to the soil surface. As the soil dries, energy availability becomes less important and the rate of soil water conduction becomes more important. The Priestly-Taylor formula, which uses only the radiant energy portion of the Penman-Monteith equation and a proportionality constant, a , has been successfully used to evaluate soil water evaporation when energy is limiting [Jackson et al., 1976; Stewart and Rouse, 1976a; Tanner and Jury, 1976; Woo, 1976; Mukammal and Neumann, 1977]. Substantial discussion has centered on the appropriate value for a . As drying progresses and soil water evaporation moves from the energy-limiting phase to the soil-limiting phase, the Priestly-Taylor approach becomes less applicable. Evaporation during the soil-limiting phase has been estimated for a number of years by using a simple relationship proportional to the square root of the time since the start of the soil-limiting phase. Jackson et al. [1976] proposed that since albedo is proportional to the surface water content of soil, the rate of change

in albedo would be indicative of that fraction of the soil surface in which water is evaporating at the soil-limiting rate. Thus, the soil surface could be proportioned into fractions, a portion of which would evaporate at the energy-limiting rate and a portion which would evaporate at the soil-limiting rate. However, Van Bavel and Hillel [1976] state that the transition to the soil-limiting phase is not due to changes in albedo, but to the hydraulic properties of the soil and to a reduction of the relative humidity at the surface to less than 1. The transition between phases can be identified by a rapid increase in the amplitude of the surface temperature. Van Bavel and Hillel propose an extension of the Penman equation by incorporating terms related to the hydraulic and thermal properties of the soil profile.

Transpiration Modification

The reduction of evapotranspiration to increase water supply or reduce irrigation requirements has been a long standing goal in arid and semi-arid regions. Most of the recent work has been directed toward modifying canopy resistance through the use of chemical antitranspirants [Kreith et al., 1975]. Several of the suggested chemicals, however, are toxic to plants or animals. In some cases, the reduction of transpiration is accompanied by a reduction in photosynthesis; the water use efficiency of the plant is, therefore, unaffected. A naturally occurring plant hormone, abscisic acid (ABA) has shown promise to be a non-toxic antitranspirant. Abscisic acid content has been shown to increase in leaves which are exposed to water stress [Vaadia, 1976] and has the effect of reducing the stomatal aperture in light [Raschke, 1975]. Nordin [1976] found that exogenous applications of ABA lowered the amplitude of transpiration in the light. Talha and Larsen [1975] found an approximately linear relationship between transpiration rate and the logarithm of the concentration of exogenously applied ABA. The magnitude and persistence of the effect was related to the ABA concentration. However, in a later study on plants subjected to water stress, Talha and Larsen [1976] concluded that once a sufficient concentration of endogenous ABA has built up in the stressed plants, no further reduction of transpiration can be expected by additional exogenous applications of ABA. Thus, ABA might be most effective as an antitranspirant at intermediate soil water potentials.

The effectiveness of ABA applications in reducing transpiration seems to be related to species. A single exogenous application of ABA has been reported to reduce transpiration for several hours in wheat plants [Bengtson et al., 1977] to 21 days in young ash seedlings [Davies and Kozlowski, 1975b]. However, the ABA content of water-stressed plants has been observed to fall rapidly to the pre-stress level upon watering while stomatal resistances remain high. Thus, there seems to be no direct correlation between residual ABA concentration and the delayed recovery of transpiration rate [Beardsell and Cohen, 1975; Bengtson et al., 1977]. There is increasing evidence that the duration of the reported reduction of transpiration cannot be explained entirely by stomatal closure [Lancaster and Mann, 1977]. Consequently,

the mechanism of ABA induced changes to transpiration rate remains obscure.

In the few studies where antitranspirants have been applied to plant communities, only modest success has been obtained in altering the areal water balance. However, Belt et al. [1977] reported a 12% increase in summer streamflow after a 5% aqueous emulsion of silicone oil was sprayed on a 26-ha catchment in Idaho.

Instrumentation and Methods

Measurement of transpiration by mature forest trees presents a number of obvious problems. One procedure, that of measuring the velocity of the sap flow in the water conducting systems of plants, has been used with varied success for over 40 years. A well developed method of measuring sap flow velocities has been to measure the velocity of heat pulses in the stem. Lassoie et al. [1977] compared the temporal and spatial variation of heat pulse velocities in Douglas-fir stems with various direct measurements of evapotranspiration. They found the technique provided good correlations with foliar water loss and was sensitive enough to detect rehydration of tissues when water loss terminated. A modification of the measuring system by Kucera et al. [1977] allows quantitative measurements of changes in the transpiration flow rate to within a time increment as small as 1 minute. This system has been successfully used to correlate changes in transpiration flow with short-term microclimate data [Cermak et al., 1976; Huzulak and Elias, 1976; Balek and Pavlik, 1977]. Another method of evaluating transpiration rates by measuring water movements in the stem is through injection of some tracer into the stem and measuring the rate and location of arrival at the transpiring surface. Using a tritium injection method, Kline et al. [1976] found a linear relationship between transpiration and sapwood area of each tree. By knowing such a relationship, the transpiration of an entire forest could be approximated by using the estimated sapwood area of the forest and the measured relationship between transpiration and sapwood area [Jordan and Kline, 1977]. The sites and pathways of water movement at the cellular level within leaves has also been traced by using monosilicic acid [Aston and Jones, 1976] and Prussian blue [Burbano et al., 1976; Pizzolato et al., 1976].

There have been several improvements in instrumentation to evaluate plant water status. New porometers have been described for measuring conductance and transpiration of conifers and other species with irregularly shaped foliage [Bingham and Coyne, 1976; Kaufmann and Ekern, 1977]. Thermocouple psychrometer instrumentation and methodology continues to be improved for measurement of leaf water potentials *in situ* [Hoffman and Hall, 1976; Brown and McDonough, 1977; Zanstra and Hagenzieker, 1977] or of excised samples [Manohar, 1977; Nelson et al., 1978] and for the measurement of soil water potential [Brown and Johnston, 1976].

The physically and biologically oriented evapotranspiration models are not practical for regional estimations because the detailed meteorological and vegetative data required are not available. The data restrictions are even more severe when such models are applied to mountainous forested

regions or to countries where meteorological data are essentially lacking. Efforts continue to develop models which utilize data which can be collected with sensors located in aircraft or spacecraft [Idso et al., 1975; Heilman et al., 1976; J.E. Jones, 1977; Kanemasu et al., 1977] or stochastic simulation of the hydrologic cycle [Magyar et al., 1978]. Though improvements are being made, estimates derived from such methodology leave much to be desired. A promising and novel approach to calculate regional evapotranspiration uses rawinsonde data which are routinely collected at about 70 stations throughout the United States [Brutsaert and Mawdsley, 1976; Mawdsley and Brutsaert, 1977]. Such application of planetary boundary layer theory to estimate evapotranspiration requires additional research into the functional form of the similarity functions for sensible heat and bulk water vapor transfer under various conditions of atmospheric stability [Brutsaert and Chan, 1978].

Future Needs

We have advanced a great deal in understanding the physical and biological controls on evapotranspiration. The ability to apply models to field situations is less successful, particularly in forested areas and in other areas where data are lacking. We are still unable to predict the effect of timber cutting, wildfire, changes in species composition, or other cultural activities on watershed water balances. In many wildland areas, we are unable to measure adequately even areal precipitation - let alone the rather detailed meteorological data required to calculate evapotranspiration with the Penman-Monteith equations.

The ability to evaluate effectively the influence of regional and local advection upon calculated evapotranspiration needs to be more strongly addressed. Our ability to calculate accurately evapotranspiration within that cover condition between bare soil and full cover is still weak, particularly as to areal water loss from scattered vegetation of different species and sizes.

Afshar A., and M. A. Marino, Model for simulating soil-water content considering evapotranspiration, J. Hydrol. 37 (3/4): 309-322, 1978.

Anderson, J. E., Transpiration and photosynthesis in saltcedar, Hydrol. Water Resour. Ariz. Southwest 7: 125-131, 1977.

Aslam, M., S. B. Lowe, and L. A. Hunt, Effect of leaf age on photosynthesis and transpiration of cassava (Manihot esculenta), Can. J. Bot. 55(17): 2288-2295, 1977.

Aston, M. J., Variation of stomatal diffusive resistance with ambient humidity in sunflower (Helianthus annuus), Aust. J. Plant Physiol. 489-501, 1976.

Aston, M. J., and M. M. Jones, A study of the transpiration surfaces of Avena sterilis L. var. algerian leaves using monosilicic acid as a tracer for water movement, Planta (Berl.) 130(2): 121-129, 1976.

Ayres, P. G., and P. Jones, Increased transpiration and the accumulation of root absorbed ⁸⁶Rb in barley leaves infected by

- Rhynchosporium secalis (leaf blotch), Physiol. Plant Pathol. 7(1): 49-58, 1975.
- Balek, J., and O. Pavlik, Sap stream velocity as an indication of the transpirational process, J. Hydrol. 34(1/2): 193-200, 1977.
- Baradas, M. W., B. L. Blad, and N. J. Rosenberg, Reflectant induced modification of soybean canopy radiation balance, V, longwave radiation balance, Aaron. J. 68(6): 848-852, 1976.
- Barlow, E. W. R., L. Boersma, and J. L. Young, Photosynthesis, transpiration and leaf elongation in corn seedlings at suboptimal soil temperatures, Agron. J. 62(1): 95-100, 1977.
- Beardsell, M. F., and D. Cohen, Relationships between water status abscisic acid levels and stomatal resistance in maize and sorghum, Plant Physiol. 56: 207-212, 1975.
- Begg, J. E., and N. C. Turner, Crop water deficits, Adv. Agron. 28: 161-217, 1976.
- Belt, G. H., J. G. King, and H. F. Haupt, Augmenting summer streamflow by use of a silicone antitranspirant, Water Resour. Res. 13(2): 267-272, 1977.
- Bengtson, C., S. O. Falk, and S. Larsson, The after-effect of water stress on transpiration rate and changes in abscisic acid content of young wheat plants, Physiol. Plant. 41(2): 149-154, 1977.
- Biddington, N. L., and T. H. Thomas, Influence of different cytokinins on the transpiration and senescence of excised oat leaves, Physiol. Plant. 42(4): 369-374, 1978.
- Bielorai, H., and P. A. M. Hopmans, Recovery of leaf potential, transpiration, and photosynthesis of cotton during irrigation cycles, Agron. J. 67(5): 629-632, 1975.
- Bilan, M. V., C. T. Hogan, and H. B. Carter, Stomatal opening, transpiration, and needle moisture in loblolly pine seedlings from two Texas seed sources, Forest Sci. 23(4): 437-462, 1977.
- Bingham, G. E., and P. I. Coyne, A portable temperature-controlled steady-state porometer for field measurements of transpiration and photosynthesis, Photosynthetica 11(1): 148-160, 1977.
- Blad, B. L., and N. J. Rosenberg, Evaluation of resistance and mass transport evapotranspiration models requiring canopy temperature data, Agron. J. 68(5): 764-769, 1976.
- Blake, G. R., Estimates of evapotranspiration for grass cover, Minn. Univ. Agric. Ext. Serv. Soil Ser. 99: 237-241, 1977.
- Bloeman, G. W., A high-accuracy recording pan-evaporimeter and some of its possibilities, J. Hydrol. 39(1/2): 159-173, 1978.
- Bolsenga, S. J., Estimating energy budget components to determine Lake Huron evaporation, Water Resour. Res. 11(5): 661-666, 1975.
- Bouwer, H., Predicting reduction in water losses from open channels by phreatophyte control, Water Resour. Res. 11(1): 96-101, 1975.
- Bradbury, I. K., and D. C. Malcolm, The effect of phosphorus and potassium on transpiration leaf diffusive resistance and water use efficiency in Sitka spruce (Picea sitchensis) seedlings, J. Appl. Ecol. 14(2): 631-642, 1977.
- Brady, R. A., S. M. Goltz, W. L. Powers, and E. T. Kanemasu, Relation of soil water potential to stomatal resistance of soybean, Agron. J. 67: 97-99, 1975.
- Brown, K. W., W. R. Jordan, and J. C. Thomas, Water stress induced alternations of the stomatal response to decreases in leaf water potential, Plant Physiol. 37: 1-5, 1976.
- Brown, R. W., and R. S. Johnston, Extended field use of screen-covered thermocouple psychrometers, Agron. J. 68(6): 995-996, 1976.
- Brown, R. W., and W. T. McDonough, Thermocouple psychrometer for in situ leaf water potential determinations, Plant Soil 48(1): 5-10, 1977.
- Brutsaert, W., A theory for local evaporation (or heat transfer) from rough and smooth surfaces at ground level, Water Resour. Res. 11(4): 543-550, 1975a.
- Brutsaert, W., The roughness length for water vapor, sensible heat, and other scalars, J. Atmos. Sci. 32(10): 2028-2031, 1975b.
- Brutsaert, W., The determination of regional evapotranspiration by means of standard meteorological data, Sch. Civil and Environ. Eng., Cornell Univ., Ithaca, N.Y., Proj. B-052-NT, 47 p., 1976.
- Brutsaert, W., and F. K. Chan, Similarity functions D for water vapor in the unstable atmospheric boundary layer, Boundary-Layer Meteorol. 14: 441-456, 1978.
- Brutsaert, W., and J. A. Mawdsley, The applicability of planetary boundary-layer theory to calculate regional evapotranspiration, Water Resour. Res. 12(5): 852-858, 1976.
- Burbano, J. L., T. D. Pizzolato, P. R. Morey, and J. D. Berlin, An application of the Prussian blue technique to a light microscope study of water movement in transpiring leaves of cotton (Gossypium hirsutum L.), J. Exp. Bot. 27(96): 134-144, 1976.
- Butler, D. R., Estimation of the transpiration rate in an apple orchard from net radiation and vapor pressure deficit measurements, Agric. Meteorol. 16(2): 277-289, 1976.
- Calder, I. R., The measurement of water losses from a forested area using a "natural" lysimeter, J. Hydrol. 30: 311-325, 1976.
- Calder, I. R., A model of transpiration and interception loss from a spruce forest in Plynlimon, Central Wales, J. Hydrol. 33(34): 247-265, 1977.
- Calder, I. R., Transpiration observations from a spruce forest and comparisons with predictions from an evaporation model, J. Hydrol. 38(1/2): 33-47, 1978.
- Campbell, G. S., and G. A. Harris, Water relations and water use patterns for Artemisia tridentata Nutt. in wet and dry years, Ecology 58(3): 652-659, 1977.
- Campbell, R. B., and C. J. Phene, Estimating potential evapotranspiration from screened pan evaporation, Agric. Meteorol. 16(3): 343-352, 1976.
- Canny, M. J., Flow and transport in plants, Annu. Rev. Fluid Mech. 9: 275-296, 1977.
- Carvalho, H. O., D. K. Cassel, and A. Bauer, Water losses from an irrigated soybean field

- by deep percolation and evapotranspiration, Water Resour. Res. 11(2): 267, 1975.
- Cermak, J., M. Palat, and M. Penka, Transpiration flow rate in a full grown tree of Prunus avium L. estimated by the method of heat balance in connection with some meteorological factors, Biol. Plant. 18(2): 111-118, 1976.
- Chatterton, N. J., W. W. Hanna, J. B. Powell, and D. R. Lee, Photosynthesis and transpiration of bloom and bloomless sorghum, Can. J. Plant Sci. 55(2): 641-643, 1975.
- Coleman, G., and D. G. DeCoursey, Sensitivity and model variance analysis applied to some evaporation and evapotranspiration models, Water Resour. Res. 12(5): 873-879, 1976.
- Crow, F. R., and A. C. Mitchell, Jr., Wind effects on chemical films for evaporation suppression at Lake Hefner, Water Resour. Res. 11(3): 493-495, 1975.
- Culler, R. C., R. L. Hanson, and J. E. Jones, Relation of the consumptive use coefficient to the description of vegetation, Water Resour. Res. 12(1): 40-46, 1976.
- Dale, R. F., and K. L. Scheeringa, The effect of soil moisture on pan evaporation, Agric. Meteorol. 18(6): 463-474, 1977.
- Daniel, J. F., Estimating groundwater evapotranspiration from streamflow records, Water Resour. Res. 12(3): 360-364, 1976.
- Davenport, D. C., Stomatal resistance from Cuvette transpiration measurements, Bull. Wash. (State) Agric. Exp. Stn. 809: 12-15, 1975.
- Davenport, D. C., Antitranspirants aid plant cultivation, Am. Nurseryman. 145(8): 28, 30, 32, 34, 36, 1977.
- Davenport, D. C., and R. M. Hagan, Reducing phreatophyte transpiration, Hydrol. Water Resour. Ariz. Southwest 7: 141-146, 1977.
- Davenport, D. C., R. M. Hagan, and K. Uriu, Reducing transpiration to conserve water in soil and plants, Calif. Agric. 51(5): 40-41, 1977.
- Davies, W. J., and T. T. Kozlowski, Effect of applied abscisic acid and silicone on water relations and photosynthesis of woody plants, Can. J. Forest Res. 5: 90-96, 1975a.
- Davies, W. J., and T. T. Kozlowski, Effects of applied abscisic acid and plant water stress on transpiration of woody angiosperms, Forest Sci. 21(2): 191-195, 1975b.
- Davis, E. A., Transpiration reduction of shrub live oak by picloram, Forest Sci. 24(2): 217-221, 1978.
- Denmead, O. T., and B. D. Millar, Field studies of the conductance of wheat leaves and transpiration, Agron. J. 68(2): 307-311, 1976.
- Eagleson, P. S., Climate, soil, and vegetation, 1, introduction to water balance dynamics, Water Resour. Res. 14(5): 705-712, 1978a.
- Eagleson, P. S., Climate, soil, and vegetation, 4, the expected value of annual evapotranspiration, Water Resour. Res. 14(5): 731-737, 1978b.
- Eagleson, P. S., Climate, soil, and vegetation, 6, dynamics of the annual water balance, Water Resour. Res. 14(5): 749-764, 1978c.
- Eagleson, P. S., Climate, soil, and vegetation, 7, a derived distribution of annual water yield, Water Resour. Res. 14(5): 765-776, 1978d.
- Ekern, P. C., Evaporation and transpiration, U.S. Natl. Rep. 15th Gen. Assem. IUGG, EOS, 52: IUGG 286-291, 1971.
- Ekern, P. C., Drip irrigation of sugarcane measured by hydraulic lysimeters, Kunia, Oahu, Water Resour. Res. Cent. Univ. Hawaii, Tech. Rep. 109, 99 p., 1977.
- England, C. B., Modeling soil water hydrology under a post oak (Quercus stellata Wangenh.) - shortleaf pine (Pinus echinata Mill.) stand in east Texas, Water Resour. Res. 13(3): 683-686, 1977.
- Everett, R. L., R. O. Meewig, P. T. Tueller, and R. A. Evans, Water potential in sagebrush and shadscale communities, Northwest Sci. 51(4): 271-281, 1977.
- Feddes, R. A., and H. Zaradny, Model for simulating soil-water content considering evapotranspiration--comments, J. Hydrol. 37(3/4): 393-397, 1978.
- Feddes, R. A., P. Kowalik, K. Kolinska-Malinka, and H. Zaradny, Simulation of field water uptake by plants using a soil water dependent root extraction function, J. Hydrol. 31: 13-26, 1976.
- Federer, C. A., Evapotranspiration, Reviews of Geophysics and Space Physics 13(3): 442-445, 1975.
- Federer, C. A., Differing diffusive resistance and leaf development may cause differing transpiration among hardwoods in spring, Forest Sci. 22(3): 359-364, 1976.
- Federer, C. A., Leaf resistance and xylem potential differ among broadleaved species, Forest Sci. 23: 411-419, 1977.
- Federer, C. A., and G. W. Gee, Diffusion resistance and xylem potential in stressed and unstressed northern hardwood trees, Ecology 57, 975-984, 1976.
- Federer, C. A., and D. Lash, Simulated streamflow response to possible differences in transpiration among species of hardwood trees, Water Resour. Res. 14(6): 1089-1097, 1978.
- Ferree, D. C., and F. R. Hall, Effects of growth regulators and multiple applications of pesticides on net photosynthesis and transpiration of greenhouse-grown apple trees, J. Am. Soc. Hortic. Sci. 103(1): 61-64, 1978.
- Fetcher, N., Patterns of leaf resistance to lodgepole pine transpiration in Wyoming, Ecology 57(2): 339-345, 1976.
- Fisher, J. T., and C. P. P. Reid, Transpiration of Arceuthobium americanum and Pinus contorta under increasing levels of water stress, Proc. Am. Phytopathol. Soc. 2: 29-30, 1975.
- Forde, B. J., K. J. Mitchell, and E. A. Edge, Effect of temperature, vapor-pressure deficit, and irradiance on transpiration rates of maize, paspalum, westerwolds and perennial ryegrasses, peas, white clover and lucerne, Aust. J. Plant Physiol. 4(6): 889-900, 1977.
- Frank, A. B., and R. E. Barker, Rates of photosynthesis and transpiration and diffusive resistance of six grasses grown under controlled conditions, Agron. J. 68(3): 487-490, 1976.
- Fritschen, L. J., J. Hsia, and P. Doraiswamy, Evapotranspiration of a Douglas fir determined with a weighing lysimeter, Water Resour. Res. 13(1): 145-148, 1977.

- Gale, J., A. Kaplan, and T. Tako, Systematic errors in measurement of transpiration and photosynthesis by gas analyses with varying oxygen: nitrogen ratios in the background gas, J. Exp. Bot. 26(94): 702-704, 1975.
- Gash, J. H. C., and J. B. Stewart, The average surface resistance of a pine forest derived from Bowen ratio measurements, Boundary-Layer Meteorol. 8: 453-464, 1975.
- Gash, J. H. C., and J. B. Stewart, The evaporation from Thetford Forest during 1975, J. Hydrol. 35(34): 385-396, 1977.
- Gay, L. W., and T. W. Sammis, Estimating phreatophyte transpiration, Hydrol. Water Resour. Ariz. Southwest 7: 133-139, 1977.
- Grant, D. R., Comparison of evaporation from barley with Penman estimates, Agric. Meteorol. 15(1): 49-60, 1975.
- Gravatt, B. A., J. C. O'Toole, P. M. Ludford, and J. L. Ozburn, System for measuring photosynthetic and transpiration rates of intact leaves under controlled conditions, Lab. Pract. 25(5): 313-316, 1976.
- Griffing, C. G., and S. J. Ursic, Ethephon advances loblolly pine needle cast, Forest Sci. 23(3): 351-354, 1977.
- Hall, A. E., and M. R. Kaufmann, Regulation of water transport in the soil-plant-atmosphere continuum, in Ecol. Stud., Analysis and Synthesis 12, edited by D. M. Gates and R. B. Schmerl, pp. 187-202, Springer-Verlag, Berlin, 1975.
- Hall, A. E., E. D. Schultz, and O. L. Lange, Current perspectives of steady-state stomatal responses to environment, Water Plant Life, Ecol. Stud. 19: 169-188, 1976.
- Hamilton, J. W., Transpiration control by native clover epicuticular wax, Adv. Frontiers Plant Sci. 30: 175-187, 1975.
- Hanscom, Z. III, H. B. Johnson, and I. P. Ting, Simultaneous measurements of photosynthesis and transpiration in the field with a dual label porometer, Plant Physiol. 57(5 suppl): 106, 1976.
- Hanson, C. L., Model for predicting evapotranspiration from native rangelands in the Northern Great Plains, Trans. ASAE 19(3): 471-477, 481, 1976.
- Hasfurther, V. R., D. H. Foster, D. G. Logfren, and S. R. Jenkins, Evapotranspiration as an alternative for second home waste disposal systems, Eisenhower Consortium Bull. Eisenhower Consortium West Environ. For. Res. 1: 213-220, 1975.
- Hatfield, J. L., C. D. Stanley, and R. E. Carlson, Evaluation of an electronic foliometer to measure leaf area in corn and soybeans, Agron. J. 68: 434-436, 1976.
- Heilman, J. L., and E. T. Kanemasu, An evaluation of a resistance form of the energy balance to estimate evapotranspiration, Agron. J. 68(4): 607-611, 1976.
- Heilman, J. L., E. T. Kanemasu, N. J. Rosenberg, and B. L. Blad, Thermal scanner measurement of canopy temperatures to estimate evapotranspiration, Remote Sens. Environ. 5(2): 137-145, 1976.
- Hillel, D., Simulation of evaporation from bare soil under steady and diurnally fluctuating evaporativity, Soil Sci. 120(3): 230-237, 1975.
- Hillel, D., On the role of soil moisture hysteresis in the suppression of evaporation from bare soil under diurnally cyclic evaporativity, Soil Sci. 122(6): 309-314, 1976.
- Hinckley, T. M., M. O. Schroeder, J. E. Roberts, and D. N. Bruckerhoff, Effect of several environmental variables and xylem pressure potential on leaf surface resistance in white oak, Forest Sci. 21(2): 201-211, 1975.
- Hobbs, E. H., and K. K. Krogman, Using evapotranspiration data to favorably influence an irrigated environment, Environ. Aspects of Irrig. and Drain., Proc. of a Specialty Conf. p. 184-191, 1976.
- Hoffman, G. J., and A. E. Hall, Performance of the silver-foil psychrometer for measuring leaf water potential in situ, Agron. J. 68(6): 872-875, 1976.
- Hsiao, T. C., E. Acevedo, E. Fereres, and D. W. Henderson, Water stress, growth, and osmotic adjustment, Phil. Trans. R. Soc. Lond. B 273: 479-500, 1976.
- Huzulak, J., and P. Elias, The intensity of the transpiration flow in the trunk of Quercus cerris, Biologia 31(7): 537-543, 1976.
- Idle, D. B., The effects of leaf position and water vapor density deficit on the transpiration rate of detached leaves, Ann. Bot. 41(175): 959-968, 1977.
- Idso, S. B., R. D. Jackson, and R. J. Reginato, Estimating evaporation: a technique adaptable to remote sensing, Science 189(4207): 991-992, 1975.
- Idso, S. B., R. D. Jackson, and R. J. Reginato, Estimating evaporation: difficulties of applicability in different environments, Science 196(4296): 1356, 1977.
- Ismail, M. M., and J. B. Storey, The effect of water stress on the accumulation of abscisic acid in pecan leaves (Carya illinoensis (Wang) K. Koch), Hort. Sci. 13(3, sect. 2): 345, 1978.
- Item, H., A model for the water regime of coniferous forest and grassland, J. Hydrol. 37(3/4): 323-332, 1978.
- Jackson, R. D., S. B. Idso, and R. J. Reginato, Calculation of evaporation rates during the transition from energy-limiting to soil-limiting phases using albedo data, Water Resour. Res. 12(1): 23-26, 1976.
- Jarvis, P. G., The interpretation of the variations in leaf water potential and stomatal conductance found in canopies in the field, Phil. Trans. R. Soc. Lond. B 273: 593-610, 1976.
- Jensen, M. E., and J. L. Wright, The role of evapotranspiration models in irrigation scheduling, Trans. ASAE 21(1): 82-87, 1978.
- Johns, G. G., Transpirational, leaf area, stomatal and photosynthetic responses to gradually induced water stress in four temperate herbage species, Aust. J. Plant Physiol. 5(2): 113-125, 1977.
- Johnson, D. A., and R. W. Brown, Psychrometric analysis of turgor pressure response: a possible technique for evaluating plant water stress resistance, Crop Sci. 17(4): 507-510, 1977.
- Jones, H. G., Crop characteristics and the ratio between assimilation and transpiration, J. Appl. Ecol. 13(2): 605-622, 1976.

- Jones, H. G., Transpiration in barley lines with differing stomatal frequencies, J. Exp. Bot. 28(120): 162-168, 1977.
- Jones, J. E., Calculation of evapotranspiration using color-infrared photography, U.S. Geol. Surv., Prof. Pap. 655-0, 45 p. 1977.
- Jordan, C. F., and J. R. Kline, Transpiration of trees in a tropical rain forest, J. Appl. Ecol. 14(3): 853-860, 1977.
- Jury, W. A., and C. B. Tanner, Advection modification of the Priestley and Taylor evapotranspiration formula, Agron. J. 67(6): 840-842, 1975.
- Kalma, J. D., P. M. Fleming, and G. F. Byrne, Estimating evaporation: difficulties of applicability in different environments, Science 196(4296): 1354-1355, 1977.
- Kanemasu, E., Great Plains evapotranspiration by a resistance model using remotely sensed thermal imagery, project completion report, Kansas Water Resour. Res. Inst., Dept. Agric. Eng., Manhattan, Kan., 154 p., 1975.
- Kanemasu, E. T., L. R. Stone, and W. L. Powers, Evapotranspiration model tested for soybean and sorghum, Agron. J. 68(4): 569-572, 1976.
- Kanemasu, E. T., J. L. Heilman, J. O. Bagley, and W. L. Powers, Using Landsat data to estimate evapotranspiration of winter wheat, Environ. Manage. 1(6): 515-520, 1977.
- Kaufmann, M. R., and A. N. Echard, A portable instrument for rapidly measuring conductance and transpiration of conifers and other species, Forest Sci. 23(2): 227-237, 1977.
- Khairi, M. M. A., and A. E. Hall, Temperature and humidity effects on net photosynthesis and transpiration of citrus, Physiol. Plant. 36(1): 29-34, 1976a.
- Khairi, M. M. A., and A. E. Hall, Comparative studies of net photosynthesis and transpiration of some citrus species and relatives, Physiol. Plant. 36(1): 35-39, 1976b.
- King, L. D., A. J. Leyshon, and L. R. Webber, Application of municipal refuse and liquid sewage sludge to agricultural land, II, lysimeter study, J. Environ. Qual. 6(1): 67-71, 1977.
- Kline, J. R., K. L. Reed, R. H. Waring, and M. L. Stewart, Field measurement of transpiration in Douglas-fir, J. Appl. Ecol. 13(1): 273-283, 1976.
- Kreith, F., A. Taori, and J. E. Anderson, Persistence of selected antitranspirants, Water Resour. Res. 11(2): 281-286, 1975.
- Kucera, J., J. Cermak, and M. Penka, Improved thermal method of continual recording the transpiration flow rate dynamics, Biol. Plant. 19(6): 413-420, 1977.
- Lancaster, J. E., and J. D. Mann, Extrastomatal control of transpiration in leaves of yellow lupin (Lupinus luteus var. Weiko III) after drought or abscisic acid treatment, J. Exp. Bot. 28(107): 1373-1379, 1977.
- Landsberg, J. J., T. W. Blanchard, and B. Warrit, Studies on the movement of water through apple trees, J. Exp. Bot. 27(99): 579-596, 1976.
- Lange, O. L., Plant water relations, Prog. Bot. 37: 78-97, 1975:
- Langford, K. J., and J. L. McGuinness, Using a mathematical model to assess the hydrological effects of land-use change, ARS-NC-31, U.S. Dep. of Agr., Washington, D.C., 1976.
- Lassoie, J. P., D. R. M. Scott, and L. J. Fritschen, Transpiration studies in Douglas-fir using the heat pulse technique, Forest Sci. 23(3): 377-390, 1977.
- Lauenroth, W. K., and P. L. Sims, Evapotranspiration from a shortgrass prairie subjected to water and nitrogen treatments, Water Resour. Res. 12(3): 437-442, 1976.
- Luebs, R. E., A. E. Laag, and P. A. Nash, Evapotranspiration of dryland barley with different plant spacing patterns, Agron. J. 67(3): 339-342, 1975.
- Magyar, P., A. N. Shahane, D. L. Thomas, and P. Bock, Simulation the hydrologic cycle using atmospheric water vapor transport data, J. Hydrol. 37(1/2): 111-128, 1978.
- Manning, C. E., D. G. Miller, and I. D. Teare, Effect of moisture stress on leaf anatomy and water-use efficiency of peas, J. Am. Soc. Hort.Sci. 102(6): 756-760, 1977.
- Manogaran, C., Actual evapotranspiration and the natural range of loblolly pine, Forest Sci. 21(4): 339-340, 1975.
- Manohar, M. S., A versatile Peltier psychrometer and evaluation of leaf water potential and its components during water stress cycles in some species, Z. Pflanzenphysiol. 84(2): 147-158, 1977.
- Martin, T. J., F. E. Stuckey, G. R. Safir, and A. H. Ellingboe, Reduction of transpiration from wheat caused by germinating conidia of Erysiphe graminis f. sp. tritici, Physiol. Plant Pathol. 7(1): 71-77, 1975.
- Mawdsley, J. A., and W. Brutsaert, Determination of regional evapotranspiration from upper air meteorological data, Water Resour. Res. 13(3): 539-548, 1977.
- McDaniel, G. L., and M. G. Miller, Transpiration of snapdragon under southern summer greenhouse conditions, HortSci. 11(4): 366-368, 1976.
- McKeon, G. M., and C. W. Rose, Estimating evaporation: difficulties of applicability in different environments, Science 196(4296): 1355-1356, 1977.
- McNaughton, K. G., Comment of "The evaporation of intercepted rainfall from a forest stand: an analysis by simulation" by Charles E. Murphy, Jr. and Kenneth R. Knoerr, Water Resour. Res. 12(5): 1081-1082, 1976.
- Millar, B. D., and O. T. Denmead, Water relations of wheat leaves in the field, Agron. J. 68: 303-307, 1976.
- Minshall, W. H., Stimulation of transpiration by nitrogenous materials, Can. J. Bot. 53(13): 1259-1265, 1975.
- Moore, D. G., M. L. Horton, M. J. Russell, and V. I. Myers, Evaluation of thermal X/5-detector Skylab S-192 data for estimating evapotranspiration and thermal properties of soils for irrigation management, Proc. of the NASA Earth Resour. Surv. Sym. 1st(1-D): 2561-2583, 1975.
- Morton, F. I., Estimating evaporation and transpiration from climatological observations, J. Appl. Meteorol. 14(4): 488-497, 1975.
- Morton, F. I., Climatological estimates of evapotranspiration, J. Hydraul. Div., Am. Soc. Civil Eng. 102(HY3): 275-291, 1976.

- Morton, F. I., Estimating evapotranspiration from potential evaporation: practicality of an iconoclastic approach, J. Hydrol. 38 (1/2): 1-32, 1978.
- Mukammal, E. I., and H. H. Neumann, Application of the Priestley-Taylor evaporation model to assess the influence of soil moisture on the evaporation from a large weighing lysimeter and class A pan, Boundary-Layer Meteorol. 12(2): 243-256, 1977.
- Murphy, C. E., and K. R. Knoerr, The evaporation of intercepted rainfall from a forest stand: an analysis by simulation, Water Resour. Res. 11(2): 273-280, 1975.
- Nelsen, C. E., G. R. Safir, and A. D. Hanson, Water potential in excised leaf tissue: comparison of a commercial dew point hygrometer and a thermocouple psychrometer on soybean, wheat, and barley, Plant Physiol. 61(1): 131-133, 1978.
- Niemann, E. G., W. Kuhn, and A. K. Kaul, Nuclear techniques for determining biomass production, evaporation and transpiration, root development and nutritional value in plant breeding, Tracer Tech. for Plant Breeding Proc. of a Panel, p. 79-83, 1974. (pub. 1975)
- Nkemdirim, L. C., Crop development and water loss--a case study over a potato crop, Agric. Meteorol. 16(3): 371-388, 1976.
- Nordin, A., Effects of water stress and abscisic acid on transpiration regulation in wheat, Physiol. Plant. 38(4): 233-239, 1976.
- O'Connor, G. A., and C. Cull, An evaporation chamber with constant suction, Soil Sci. Soc. Am. J. 40(4): 618-619, 1976.
- Parlange, J.-Y., and D. E. Aylor, Response of an unsaturated soil to forest transpiration, Water Resour. Res. 11(2): 319-323, 1975.
- Parmele, H., and L. Jacoby, Estimating evapotranspiration under nonhomogeneous field conditions, U.S. Agric. Res. Serv. Northeastern Region ARS-NE-51, 61 p., 1975.
- Peavy, B. A., and W. E. Dressler, Transpiration heat transfer in thermal energy storage devices, U.S. Dept. of Commerce, Nat. Bur. Standards, NBSIR 77-1237, 26 p. Washington, D.C., 1977.
- Pegelow, E. J., Jr., D. R. Buxton, R. E. Briggs, H. Muramoto, and W. G. Gensler, Canopy photosynthesis and transpiration of cotton as affected by leaf type, Crop Sci. 17(1): 1-4, 1977.
- Pereira, J. S., and T. T. Kozlowski, Diurnal and seasonal changes in water balance of Acer saccharum and Betula papyrifera, Physiol. Plant. 43(1): 19-30, 1978.
- Phene, C. J., and R. B. Campbell, Automating pan evaporation measurements for irrigation control, Agric. Meteorol. 15(2): 181-191, 1975.
- Phillips, D. W., Evaluation of evaporation from Lake Ontario during IFYGL by a modified mass transfer equation, Water Resour. Res. 14(2): 197-205, 1978.
- Pizzolato, T. D., J. L. Burbano, J. D. Berlin, P. R. Morey, and R. W. Pease, An electron microscope study of the path of water movement in transpiring leaves of cotton (Gossypium hirsutum L.), J. Exp. Bot. 27(96): 145-161, 1996.
- Raschke, K., Stomatal action, Ann. Rev. Plant Physiol. 26: 309-340, 1975.
- Raschke, K., How stomata resolve the dilemma of opposing priorities, Phil. Trans. R. Soc. Lond. B 273: 551-560, 1976.
- Rawson, H. M., Agronomic and physiological responses of soybean and sorghum crops to water deficits, IV, photosynthesis, transpiration and water use efficiency of leaves, Aust. J. Plant Physiol. 5(2): 195-209, 1978.
- Rawson, H. M., and R. G. Woodward, Photosynthesis and transpiration in dicotyledonous plants, I, expanding leaves of tobacco and sunflower, Aust. J. Plant Physiol. 3(2): 247-256, 1976.
- Rawson, H. M., J. E. Begg, and R. G. Woodward, The effect of atmospheric humidity on photosynthesis, transpiration and water use efficiency of leaves of several plant species, Planta 134(1): 5-10, 1977.
- Regehr, D. L., F. A. Bazzaz, and W. R. Boggess, Photosynthesis, transpiration and leaf conductance of Populus deltoides in relation to flooding and drought, Photosynthetica 9(1): 52-61, 1975.
- Reicosky, D. C., and D. B. Peters, A portable chamber for rapid evapotranspiration measurements on field plots, Agron. J. 69(4): 729-732, 1977.
- Reicosky, D. C., C. W. Doty, and R. B. Campbell, Evapotranspiration and soil water movement beneath the root zone of irrigated and nonirrigated millet (Panicum miliaceum), Soil Sci. 124(2): 95-101, 1977.
- Reid, W. S., and R. L. Desjardins, A continuous recording black porous disc atmometer-capacitance method, J. Agric. Eng. Res. 21(4): 443-446, 1976.
- Reid, W. S., D. J. Buckley, and R. L. Desjardins, A continuous recording black porous disc atmometer--photo-electric servo method, Trans. ASAE 18: 554, 1975.
- Reid, W. S., R. L. Desjardins, and E. Small, A six chamber individual plant microenvironment cabinet, Trans. ASAE 20(6): 1062-1066, 1977.
- Ritchie, G. A., and T. N. Hinckley, The pressure chamber as an instrument for ecological research, Adv. Ecol. Res. 9: 165-254, 1975.
- Rogers, J. S., and J. F. Bartholic, Estimated evapotranspiration and irrigation requirements for citrus, Soil Crop Sci. Soc. Fla. Proc. 35: 111-117, 1976.
- Rolfe, G. L., and F. A. Bazzaz, Effect of lead contamination on transpiration and photosynthesis of loblolly pine and autumn olive, Forest Sci. 21(1): 33-35, 1975.
- Rosenthal, W. D., E. T. Kanemasu, R. J. Raney, and L. R. Stone, Evaluation of an evapotranspiration model for corn, Agron. J. 69(3): 461-464, 1977.
- Rouse, W. R., P. F. Mills, and R. B. Stewart, Evaporation from high latitudes, Water Resour. Res. 13(6): 909-914, 1977.
- Rutter, A. J., The hydrological cycle in vegetation, Vegetation and the Atmosphere 1: 111-154, 1975.
- Rutter, A. J., A. J. Morton, and P. C. Robins, A predictive model of rainfall interception in forests, II, generalization of the model and comparison with observations in some

- coniferous and hardwood stands, J. Appl. Ecol. 12: 367-380, 1975.
- Sartz, R. S., and M. D. Knighton, Soil water depletion after four years of forest regrowth in southwestern Wisconsin, USDA For. Serv. Res. Note NC-230, 3 p., 1978.
- Saxton, K. E., Sensitivity analysis of the combination evapotranspiration equation, Agric. Meteorol. 15(3): 343-353, 1975.
- Scholl, D. G., Soil moisture flux and evapotranspiration determined from soil hydraulic properties in a chaparral stand, Soil Sci. Soc. Am. J. 40(1): 14-18, 1976.
- Seaton, K. A., J. J. Landsberg, and R. H. Sedgley, Transpiration and leaf water potentials of wheat in relation to changing soil water potential, Aust. J. Agric. Res. 28(3): 355-367, 1977.
- Sheriff, D. W., The effect of humidity on water uptake by, and viscous flow resistance of, excised leaves of a number of species: physiological and anatomical observations, J. Exp. Biol. 28(107): 1399-1407, 1977a.
- Sheriff, D. W., Evaporation sites and distillation in leaves, Ann. Bot. 41(175): 1081-1082, 1977b.
- Shimshi, D., and J. Ephrat, Stomatal behavior of wheat cultivars in relation to their transpiration, photosynthesis, and yield, Agron. J. 67(3): 326-331, 1975.
- Shirazi, G. A., J. F. Stone, and C. M. Bacon, Oscillatory transpiration in a cotton plant: An IBM/CSMP computer simulation, Tech. Bull. T-143, 27 p. Okla. Univ. Exp. Sta., Stillwater, 1976a.
- Shirazi, G. A., J. F. Stone, and C. M. Bacon, Oscillatory transpiration in a cotton plant, II, a model, J. Exp. Bot. 27(99): 619-633, 1976b.
- Shirazi, G. A., J. F. Stone, and G. W. Todd, Oscillatory transpiration in a cotton plant, 1, experimental characterization, J. Exp. Bot. 27(99): 608-618, 1976.
- Shuttleworth, W. J., The concept of intrinsic surface resistance; energy budgets at a partially wet surface, Boundary-Layer Meteorol. 8: 81-99, 1975.
- Sinclair, T. R., C. E. Murphy, Jr., and K. R. Knoerr, Development and evaluation of simplified models for simulating canopy photosynthesis and transpiration, J. Appl. Ecol. 13(3): 813-829, 1976.
- Singh, E. P., and E. N. Whitson, Evapotranspiration and water use efficiency by soybean lines differing in growth habit, Agron. J. 68(5): 834-835, 1976.
- Sivakumar, M. V. K., Prediction of leaf area index in soya bean (Glycine max. (L.) Merrill), Ann. Bot. 42(177): 251-253, 1978.
- Slabbers, P. J., Surface roughness of crops and potential evapotranspiration, J. Hydrol. 34(1/2): 181-192, 1977.
- Staple, W. J., Prediction of evaporation from columns of soil during alternate periods of wetting and drying, Soil Sci. Soc. Am. J. 40(5): 756-761, 1976.
- Sterne, R. E., M. R. Kaufmann, and G. A. Zentmyer, Environmental effects on transpiration and leaf water potential in avocado, Physiol. Plant. 41(1): 1-6, 1977.
- Stewart, J. B., Evaporation from the wet canopy of a pine forest, Water Resour. Res. 13: 915-921, 1977.
- Stewart, R. B., and W. R. Rouse, Simple models for calculating evaporation from dry and wet tundra surfaces, Arct. Alp. Res. 8(3): 263-274, 1976a.
- Stewart, R. B., and W. R. Rouse, A simple method for determining the evaporation from shallow lakes and ponds, Water Resour. Res. 12(4): 623-628, 1976b.
- Stiles, W., Enclosure method for measuring photosynthesis, respiration, and transpiration of crops in the field, Grassl. Res. Inst. Tech. Rep. 18: 1-42, 1977.
- Stone, F., Evapotranspiration reduction by field geometry effects, Okla. Agric. Exp. Sta., Rpt. B-029-OKLA, 93 p., 1976.
- Storr, D., and G. den Hartog, Gamma--the psychrometer non-constant, J. Appl. Meteorol. 14: 1397-1398, 1975.
- Stricker, H., and W. Brutsaert, Actual evapotranspiration over a summer period in the "Hupsel catchment", J. Hydrol. 39(1/2): 139-157, 1978.
- Sumayao, C. R., T. Hodges, and E. T. Kanemasu, Effect of soil moisture on transpiration and NCE of Sorghum, Grain Sorghum Res. Util. Conf. 10th: 61, 1977.
- Sumayao, C. R., E. T. Kanemasu, and T. Hodges, Soil moisture effects on transpiration and net carbon dioxide exchange of sorghum, Agric. Meteorol. 18(6): 401-408, 1977.
- Swift, L. W., Jr., W. T. Swank, J. B. Mankin, R. J. Luxmoore, and R. A. Goldstein, Simulation of evapotranspiration and drainage from mature and clear-cut deciduous forests and young pine plantation, Water Resour. Res. 11(5): 667-673, 1975.
- Talha, M., and P. Larsen, Effect of abscisic acid on the transpiration of Zea mays, Physiol. Plant. 33(1): 66-70, 1975.
- Talha, M., and P. Larsen, Effect of abscisic acid at different levels of soil water potential on the transpiration of Zea mays, Physiol. Plant. 37(2): 104-106, 1976.
- Tan, C. S., and T. A. Black, Factors affecting the canopy resistance of a Douglas-fir forest, Boundary-Layer Meteorol. 10: 475-488, 1976.
- Tanner, C. B., and W. A. Jury, Estimating evaporation and transpiration from a row crop during incomplete cover, Agron. J. 68(2): 239-243, 1976.
- Thom, A. S., and H. R. Oliver, On Penman's equation for estimating regional evaporation, Quart. J. Roy. Meteorol. Soc. 103: 345-357, 1977.
- Thompson, D. R., and T. M. Hinckley, A simulation of water relations of white oak based on soil moisture and atmospheric evaporative demand, Can. J. For. Res. 7(2): 400-409, 1977.
- Thorpe, M. R., Net radiation and transpiration of apple trees in rows, Agric. Meteorol. 19(1): 41-57, 1978.
- Tromble, J. M., Water requirements for mesquite (Prosopis juliflora), J. Hydrol. 34(1/2): 171-179, 1977.
- Turner, N. C., Concurrent comparisons of stomatal behavior, water status, and evaporation of maize in soil at high or low

- water potential, Plant Physiol. 55(5): 932-936, 1975.
- Vaadia, Y., Plant hormones and water stress, Phil. Trans. R. Soc. Lond. B 273: 513-522, 1976.
- Van Bavel, C. H. M., and D. I. Hillel, Calculating potential and actual evaporation from a bare soil surface by simulation of concurrent flow of water and heat, Agric. Meteorol. 17(6): 453-476, 1976.
- Van Sambeek, J. W., and B. G. Pickard, Mediation of rapid electrical, metabolic, transpirational, and photosynthetic changes by factors released from wounds, III, measurements of CO₂ and H₂O flux, Can. J. Bot. 54(33): 2662-2671, 1976.
- Venkatachari, A., and K. A. Ready, Relationship of evapotranspiration with pan evaporation and evaluation of crop coefficient, Acta. Agron. 27(1/2): 107-110, 1978.
- Verma, S. B., and N. J. Rosenberg, Accuracy of lysimetric, energy balance, and stability-corrected aerodynamic methods of estimating above-canopy flux of CO₂, Agron. J. 67(5): 699-704, 1975.
- Verma, S. B., N. J. Rosenberg, B. L. Blad, and M. W. Baradas, Resistance energy balance method for predicting evapotranspiration: determination of boundary-layer resistance and evaluation of error effects, Agron. J. 68(5): 776-782, 1976.
- Verma, S. B., and N. J. Rosenberg, The Brown-Rosenberg resistance model of crop evapotranspiration modified tests in an irrigated sorghum field, Agron. J. 69(2): 332-335, 1977.
- Verma, S. B., N. J. Rosenberg, and B. L. Blad, Turbulent exchange coefficients for sensible heat and water vapor under advective conditions, J. Appl. Meteorol. 17(3): 330-338, 1978.
- Warhaft, Z., Heat and moisture flux in the stratified boundary layer, Quart. J. Roy. Meteorol. Soc. 102: 703-704, 1976.
- Weaver, P. L., Transpiration rates in the Elfin Forest of the Luquillo Mountains of Puerto Rico, Caribb. J. Sci. 15(1-2): 21-30, 1975.
- Weller, S. C., and D. C. Ferree, Effect of a pinolene-base antitranspirant on fruit growth, net photosynthesis, transpiration, and shoot growth of "Golden Delicious" apple trees, J. Am. Soc. Hortic. Sci. 103(1): 17-19, 1978.
- West, D. W., and D. F. Gaff, The effect of leaf water potential, leaf temperature and light intensity of leaf diffusion resistance and the transpiration of leaves of Malus sylvestris, Physiol. Plant. 38(2): 98-104, 1976.
- Westerman, P. W., B. J. Barfield, O. J. Loewer, and J. N. Walker, Evaporative cooling of a partially-wet and transpiring leaf, I, computer model and its evaluation using wind-tunnel experiments, Trans. ASAE 19(5): 881-888, 1976a.
- Westerman, P. W., B. J. Barfield, O. J. Loewer, and J. N. Walker, Evaporative cooling of a partially-wet and transpiring leaf, II, simulated effect of variations in environmental conditions, leaf properties, and surface water characteristics, Trans. ASAE 19(5): 889-893, 896, 1976b.
- Williams, M. E., and J. E. Anderson, Diurnal trends in water status, transpiration, and photosynthesis of saltcedar, Hydrol. Water Resour. Ariz. Southwest 7: 119-124, 1977.
- Woo, M-K., Evaporation and water level in the active layer, Arct. Alp. Res. 8(2): 213-217, 1976.
- Wright, J. L., and M. E. Jensen, Development and evaluation of evapotranspiration models for irrigation scheduling, Trans. ASAE 21(1): 88-91, 96, 1978.
- Zanstra, P. E., and F. Hagenzieker, Comments on the psychrometric determination of leaf water potentials in situ, Plant Soil 48(2): 347-367, 1977.
- Ziemer, R. R., Logging effects on soil moisture losses, Ph.D. thesis, Colo. State Univ., Fort Collins, Colo., 1978.