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The failure of the Penman-Monteith equation in explaining leaf transpiration

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The vast majority of current global land surface models, hydrological models and inverse approaches to deduce evaporation from remote sensing data employ an analytical solution for the latent heat flux from plant leaves derived by Monteith (1965), based on an earlier formulation for a wet surface by Penman (1948). This so-called Penman-Monteith (PM) equation was most commonly evaluated at the canopy scale, where aerodynamic and canopy resistance to water vapour are difficult to estimate, leading to various empirical corrections when scaling from leaf to canopy. Here we evaluated the PM equation directly at the leaf scale, using a controlled, insulated wind tunnel and artificial leaves with pre-defined stomatal conductance. Experimental results were consistent with a detailed leaf energy balance model, but we measured consistent deviations from PM-predicted fluxes, which pointed to fundamental problems with the PM equation. Detailed analysis of the derivation by Monteith (1965) and later amendments revealed inconsistencies concerning the effect of stomata and the two-sided exchange of sensible heat. A corrected set of analytical solutions for leaf temperature as well as latent and sensible heat flux is presented and comparison with the original PM equation indicates a major improvement in reproducing experimental results at the leaf scale. The inconsistencies in the original PM equation and its failure to reproduce experimental results at the leaf scale (for which it was originally derived) lets us conclude that the PM equation does not constitute an accurate representation of atmospheric forcing on transpiration and should be regarded as a semi-empirical equation.