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1 Transpiration of Plants: A Review of Calculation Methods

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1.0.1 The role of transpiration in the water and energy balance of the Earth

Vegetation plays a crucial role in energy and mass exchange in the Soil - Plant – Atmosphere (SWAT) continuum. Biomass production is the primary role of plants. To performe this, three main processes are involved:

1. **Photosynthesis.** This process involves utilisation of 0.002 Earth´s net radiation only. It represents 0.5 –3.5 per cent of photosyntetic active radiation incoming on green, assimilating canopy. Water amount used directly in the process of photosynthesis is negligible.

2. **Water accumulation in plants**. Estimated annual biomas production of the Earth´s ecosystems is 1837 .10^9t, which represents 282 tons per capita and year. Relating to the surface area 1 m^2, the annual average estimated Earth´s biomass production is 12 kg m^{-2}, which represents accumulated water in canopies 8 kg m^{-2}, much less in comparison to the Earth´s transpiration average, 336 kg m^{-2}, i.e. water accumulation represents 0.036 of transpirated water only.

3. **Transpiration.** This process is characterized by high intensity of water transport and associated energy consumption.

According to estimation (Baumgartner, Reichel,1975), the average water layer, evapotranspirated from the Earth surfaces is approximately 0.5 m, which consumes 0.56 of Earth surface net radiation. Transpiration represents approximately 0.7 of Earth´s evapotranspiration. e.i. 0.336 m layer of water. Transpiration thus consumes 0.4 of Earth surface net radiation as a latent heat. This means, that transpiration is probably the most important mechanizmus to regulate energy balance of the Earth. The influence of canopy structure changes, eventually drastic decrease of canopy surface have to lead to increase of an air temperature and should contribute to further desertification .

Going to Earth surface energy balance, average annual net radiation intensity is 2100 MJ m^{-2}, latent heat of evapotranspiration represents 1176 MJ m^{-2} and 924 MJ m^{-2} only is utilised for all other processess, like heating of the biosphere and photosynthesis. Over the Slovakia, the water and energy balance averages are close to Earth´s average: energy utilised for evapotranspiration is 0.53 of net radiation and transpiration represents 0.42 of net radiation. Transpiration / evapotranspiration ratio is 0.757 and evaporation / transpiration ratio is 0.43. Thus, transpiration is the key process not only in biomass production, but even in Earth´s temperature stabilisation.

From the above mentioned it follows, that transpiration as a process should influence not only plant production but air temperature too. Clearing of rainforests, urbanisation of landscape and desertification would contribute to Earth´s air temperature increasing. Therefore, it is important to calculate transpiration intensity of different transpiration surfaces to be able to assess its influence on energy balance of landscape.

1.0.2 Calculation methods

There are three groups of methods, which can be used for transpiration calculation.

1. Calculation of transpiration, using the *solution of differential equations, describing transport of water and energy in the canopy* (Budagovskij, 1964,1981,1989). System of six partial differential equations was solved. As a result of solution, there are formulas which can be used to calculate transpiration intensities even in sparse canopies as a function of vertical coordinate in a canopy. Usual limitations of another methods, which will be described later – “big leaf” canopy, i.e. transpiration is estimated just above the canopy surface only- are not restrictive here. It can be calculated intensity of transpiration along the canopy height as a function of leaf area index. The negative feature of this approach is necessity to know non – standard input data, as vertical profile of

leaf area index in a canopy, net radiation, water vapor and heat transport coefficients vertical profiles. As a particular case, there are formulas for calculation of integral transpiration intensity above the canopy surface. This approach allows to calculate interaction between soil evaporation and transpiration.

2. *Penman – Monteith equation* for dense canopy transpiration. This equation is based on “big leaf” concept, with known canopy resistance r_s (Monteith,1965).

$$LE_t = \frac{\Delta\ (R - G) + \rho\ c_p\ \frac{d}{r_a}}{\Delta + \gamma \left(1 + \frac{r_s}{r_a}\right)}$$

E_t- transpiration rate, [kg m^{-2}s^{-1}], ρ -dry air density, [kg m^{-3}], c_p- specific heat of the air at constant pressure, [J kg^{-1}K^{-1}], $d-$ air saturation deficit [Pa], r_a- bulk aerodynamic resistance, [s m^{-1}], r_c- canopy resistance [s m^{-1}], L - latent heat of vaporisation of water, [J kg^{-1}], γ - psychrometric constant [kg m^{-2}s^{2}K^{-1}], , Δ - temperature derivative of the saturated vapour pressure curve, [K^{-1}].

The specific features of different canopies transpiration in the above mentioned equation can be expressed by the net radiation term R, soil heat flux G by the canopy resistance$r_c$and by the value of aerodynamic resistance r_a. The daily courses of R should be measured, the daily totals or daily averages of R can be calculated using procedure described by Novák [1995] in which albedo of the evaporating surface plays important role. The daily courses of G were measured and used when calculating daily courses of potential evapotranspiration. Calculating daily totals of E_t, G were neglected. The aerodynamic term $r_a$is a function of zero displacement level and dynamic roughness parameter z_0, d is air saturation deficit and Δ = *d*(e_0)*/dT is* temperature derivative of the saturated vapour pressure curve.

Crucial problem of using this equation to calculate transpiration is estimation of canopy resistancer_c,which is function of variety environmental parameters. There are known tens of empirical relationships estimated and valid for specific canopies, growing in specific conditions (Jarvis, 1976, Choudhury, Monteith, 1988).

Generalisation od such relationship is not succesful until now .

1. *Semiempirical method* of transpiration calculation, using relationship between potential transpiration and leaf area index (Budagovskij, 1981, Novak, 1995)

This method was successfully used many times, to calculate components of evapotranspiration.

Penman – Monteith equation is used to calculate potential evapotranspiration $E$of „big leaf“ canopy, then $r_c$is assumed to be zero.

$$LE = \frac{\Delta\ (R - G) + \rho\ c_p\ \frac{d}{r_a}}{\Delta + \gamma}$$

Then, potential transpiration E_{tp}can be calculated as a function of potential evapotranspiration E_p and canopy leaf area index ω_0

$E_{tp} = E_p$ exp [1- exp (-β ω_0)]

The value of coefficient β = 0.463 is valid for majority of agricultural canopies; 0.45$<\beta<$0.55.

To estimate „actual“ transpiration E_t the empirically estimated relationship between the relative transpiration and soil -water content θ can be used **(**Ritchie, Burnett, 1971, Novák 1990, Feddes et al., 1999**)**.

1.0.3 Summary

Methods of transpiration calculation - briefly described - can be used, depending on expected results quality. Input data quality depends on the expected accuraccy of results. The last, semiempirical method is simple and gives results acceptable for vide range of purposes and therefore is recommended fo use.

Transpiration of plants is directly proportional to biomass production, therefore, it is vitaly important for mankind. The influence of transpiration on boundary layer air temperature is of great importance too, but its exact estimation is difficult because of vide variety of processes involved. But it is necessary to keep in mind, that natural and /or antropogenic desertification will lead to increase of air temperature of tackled territories and can influence even global circulation of the atmosphere.

1.0.4 References

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