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A TRANSPIRATION MODEL TO SCREEN LOCAL FRUIT TREE GENOTYPES FOR DROUGHT TOLERANCE

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Abstract

Temperature increases associated with climate changes has already affected the agricultural production in Mediterranean countries, in particular, due to temperature increases. Under such scenario, selections of drought tolerance traits are imperative. Among the rich apple germplasm of Albania it is possible to find resistant genotypes but their screening requires a fast method. Given that transpiration of tree crops is mainly modulated by canopy conductance and vapour pressure deficits, we developed a functional model of tree transpiration, based on sap flow which was measured using stem heat balance sap flow sensors. Using a fast modeling approach based on parameterized Penman – Monteith equation we calculated the daily transpiration dynamics in real – time. The model was tested using various apple selections as candidate rootstocks showing a good fitting between measured and modeled values (R^2 = 0.91). This transpiration model can be effectively used to screen a large number of genotypes or even seedling from a cross in fruit tree species. The structure of the model being based on sap flow together with an assessment of intercepted radiation, allow the computation of transpiration in the main fruit tree species under different climates with a degree of precision that should be greater than the standard engineering methodology which uses a single crop coefficient regardless of climate.

Keywords: *screening, drought resistance, transpiration, modelling*

Introduction

The risks of climate change for the Albanian agricultural sector are a particularly immediate and important problem because the majority of the rural population depends either directly or indirectly on agriculture for their livelihoods (Sutton et al., 2013). Improving current approaches to quantify the transpiration of fruit trees is needed for water allocation purposes and to enhance the precision of water applications under full and deficit irrigation (Villalobos et al., 2013). Furthermore, temperature increases by 1.5°C in the next decades forecasted for Albania constitute a challenge to sustainable fruit production, which considers also water usage. Under such scenario, selections of drought tolerance traits are imperative.
Models of transpiration have been developed for many species with a wide variation of physiological detail (Dekker et al., 2000). In general they are based on the calculation of canopy conductance which is often done by applying empirical models of leaf conductance (e.g. Jarvis, 1976) to canopies (Stewart, 1988). Another approach links leaf conductance to CO_2 assimilation using semi-empirical equations (e.g. Ball et al., 1987; Leuning, 1995). Overall, the complexity of many assimilation models (e.g. Farquhar et al., 1980) needed to calculate conductance preclude the wide use of approaches linking conductance to assimilation outside the academic environment (Villalobos et al. 2013). However, the development of transpiration or canopy conductance models has been hindered by the lack of accurate, long-term transpiration data at the orchard scale. In trees it is often based on

determining sap velocity using heat as a tracer. Records of sap velocity of different fruit tree species under a variety of conditions, are a prerequisite for the estimation of transpiration with sufficient accuracy as an input needed for the parameterization and experimental validation of transpiration models (Villalobos et al., 2013).
The research presented here describes a generalized, model of transpiration based on sap flow, as a potential method for fast screening of drought tolerance among the rich apple germplasm of Albania (Kullaj, 2006).

Material and Methods

For the purposes of testing the model, four local apple genotypes, the ‘Zheji’ (Sl#01), ‘Gjeçe’(Sl#02), ‘Bardhe’ (Sl#03), and ‘Kumardha’ (Sl#04) were collected from the Fruit Germplasm Collection at the Agricultural University of Tirana. These local varieties have been phenotypically described knowing to have a different degree of drought sensitivity (Kullaj, unpublished). For the drought tolerance experiments, 20 young trees (~1 m tall) propagated by shoot proliferation were grown for several weeks. To a simulated moderate-severe drought genotypes were imposed by withholding water until the pots reached 40% of full saturation and maintained for 2 weeks at this level. Using a fast modeling approach based on parameterized Penman – Monteith (PM) equation we calculated the daily transpiration dynamics in real–time. The details of the modelling procedure and equations have been already described (Kullaj et al. 2014b). The method is based on diurnal courses of variables instead of commonly used daily means (Kullaj, et al. 2014a) and a different evapotranspiration formula describing the influence of vapour pressure deficit (*D*) to stomata closure and the parameterization process is performed as a direct non–linear multi–regression analysis of P–M equation (Kullaj 2013a, b) to radiation (*R*) and *D*. This was enabled by the use of sap flow (SF) was measured using sap flow sensors EMS 62 (EMS Brno), based on SHB (stem heat balance) method (Lindroth et al. 1995; Čermak et al. 2004). Sensors were installed on shoots (12 mm thick) on the stem of 9 saplings, 3 for each genotype. The measuring interval was every minute with 1 s warm-up and storing interval every 15 minutes during the hottest period. A portable meteorological station Minikin RTHi (EMS Brno, CZ) measured the radiation (R), air temperature (*Ta*) and humidity of air (RH). *D* was calculated from vapour pressure and relative humidity. Plants were subject to water stress, beside others (high *R* and *Ta*). Using a nonlinear multiregression analysis we obtained the measured canopy transpiration and the one calculated by P-M equation. Plants were subjected to a dry period followed by full irrigation to evaluate their ability to recover.

$$E = \frac{\left(\Delta.\left(R_n - G\right) + \rho c_p D g_a\right)/\lambda}{\Delta + \gamma.(1 + \frac{g_a}{\frac{R_g}{R_g + R_o} \cdot g_{\lim}(0.5 - \frac{1}{\pi} arctg(\frac{D}{a} - b) + g_{\min}})}$$

where:
E = transpiration [mm]; Δ – slope of saturation water vapour pressure deficit [Pa/K]; Rn – net radiation [W/m^2]; G – soil heat flux [W/m^2]; ρ – density of dry air [kg/m^3]; c_p – specific heat of air [J/m^3]; D – vapor pressure deficit [Pa]; g_a – aerodynamic conductance [s/m]; λ – water heat capacity[J/kg]; γ - psychrometric constant [Pa/K]; a, b – empirical parameters; g_s – canopy (stomatal) conductance [s/m]

Results and Discussions

Based on sap flow diurnal dynamic and using the model described, we calculated the actual (measured) diurnal transpiration of four apple selections for the entire period of measurement. The graph ilustrates the diurnal dynamics of sap flow for the entire period of measurments which was characterized by a relatively stable evapotranspiration demand. To enable a comparison both as daily maximum rates as well as a total transpiration for the entire measurement period, selected statistics are reported in Table 1. The diurnal dynamics shows clearly that Sl#02 had the highest transpiration rates (0.0153 mm), whilst the other three selections have similar rates.

Table 1. Comparison of transpiration values (mm) between the four apple selections

Selections	Min	Max	Average	Total	Std. Dev.	Records
Sl#01	0	0.01018210	0.002408901	7.166481	0.00241891	2975
Sl#02	0	0.01533009	0.004116965	12.247970	0.00398802	2975
Sl#03	0	0.01178653	0.003021107	8.987795	0.00303455	2975
Sl#04	0	0.01274005	0.003287117	9.779174	0.00325232	2975

Transpiration is driven mainly by vapour pressure deficit (*D*). Figure 1 shows the dependency of transpiration to *D* as well as the modelled potential evapotranspiration (PET) calculated from meteorological sensors. Figure 2 shows the comparison of diurnal cycles of measured versus modelled transpiration. A short period was selected for better comparison of the fluctuations. Further more, a regression analysis (Figure 3) explained in more details elsewhere (Kullaj et al. 2013a,b) gives a good regression coefficient between measured and modelled data. The sensitivity analysis demonstrates that the model fits with the actual transpiration data and can be used to simulate various abiotic stresses.

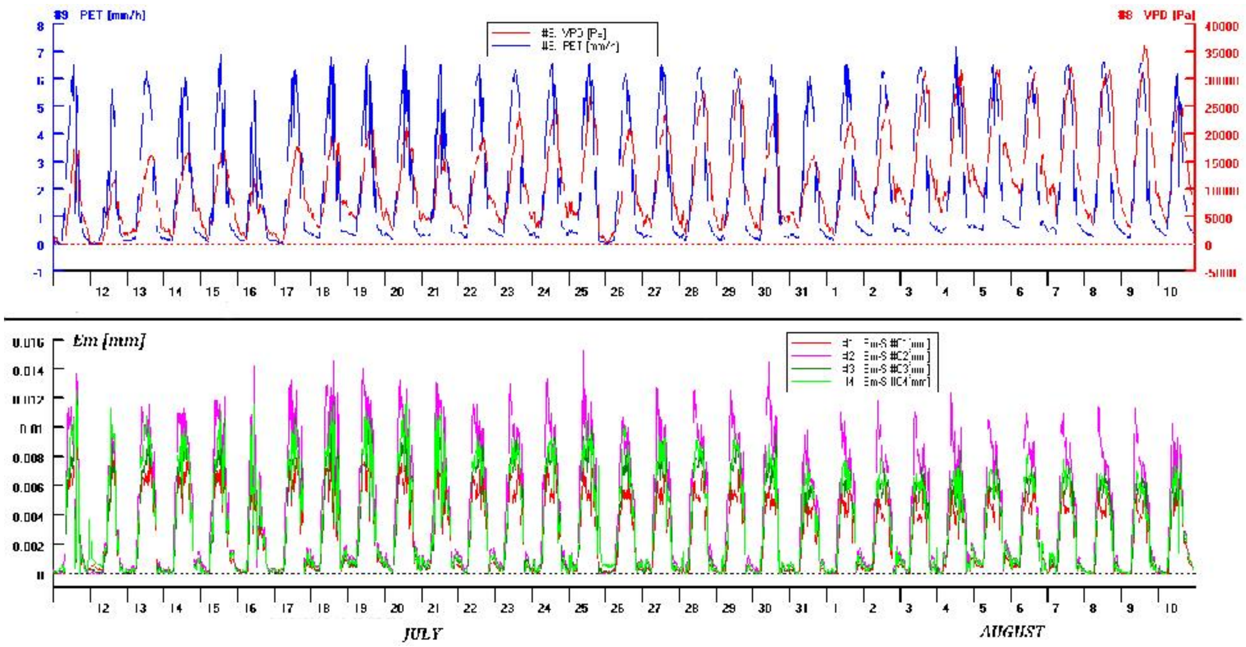

Figure 1. Dependence of transpiration values to VPD. The upper window shows also potential evapotranspiration dynamics

The model responds to the main changes on the crop-climate binomial, thus is a step forward with respect to the simpler approaches currently used for the calculation of crop water requirements. This modelling methodology is adapted for fruit trees in which E responds to the g_s, contrary to short, dense field crops or grasses, in which whole–crop E is dependent on stomatal aperture when g_s is low but as stomata begin to open, whole–canopy E soon becomes relatively insensitive to changes in g_s (Lakso, 1994). This is related to changes between the two types of crops in terms of tree boundary layer resistance, with apples having small boundary layers due to their stature and roughness of the canopy, changing the transfer rate of water vapour between the crop and the air above.

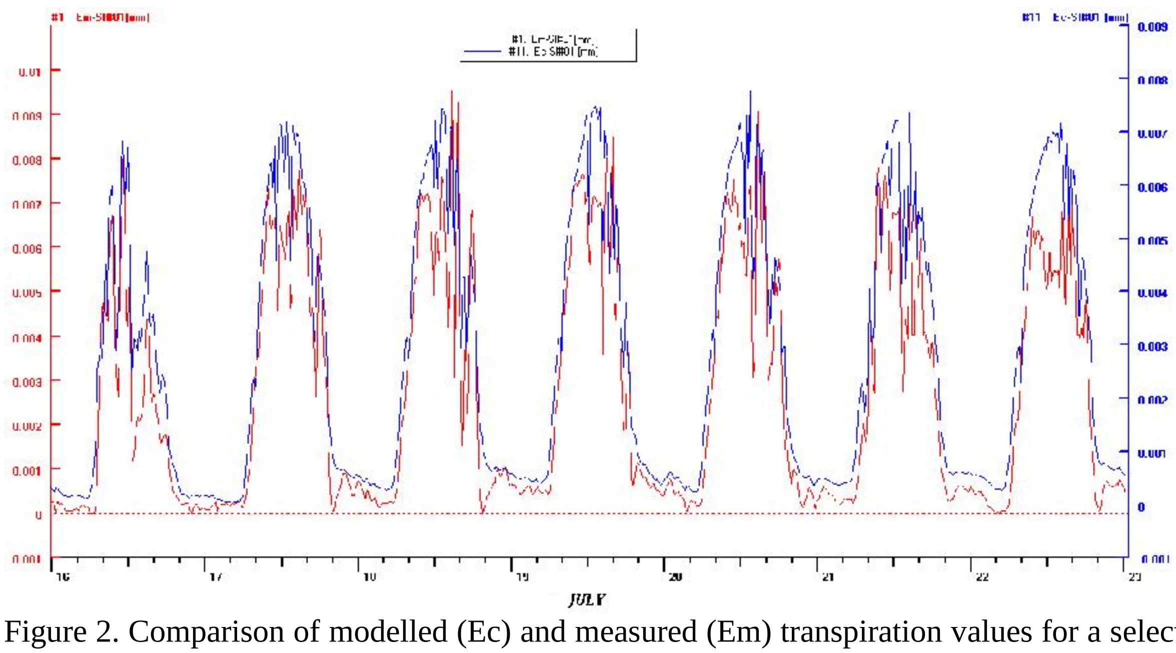

Figure 2. Comparison of modelled (Ec) and measured (Em) transpiration values for a selected period of measurement. It seems that the model fits with measured variables. However, in

particular cases we see a higher or lower prediction values, especially in days where there is a high fluctuation in meteorological variables dring sap flow.

Calculation of modelled E values in PrgmClc module is approachable directly from the fit module. The fit module estimates the time lag between radiation (VPD) and sap flow using a cross-correlation analysis. The programming code is created automatically although an editing is advisable. During the calculation, a new file with calculated canopy transpiration variable is created.

The main advantages over the standard FAO method (Allen et al., 1998) of using this model of canopy conductance to calculate transpiration are a more mechanistic approach that increases the precision of the estimate and the reduced data requirements relative to the FAO method. Solar radiation and vapour pressure deficit may also be estimated from maximum and minimum air temperature using the Hargreaves method (Hargreaves and Samani, 1985) for solar radiation and taking minimum temperature as a surrogate for dew point temperature (Villalobos et al. 2013). The model proposed here could account for the changes in canopy conductance by modifying the coefficients *a* and *b* of Eq. in proportion to atmospheric CO_2 concentration and expected changes in radiation use efficiency.

The model presented here predicts that the increase in transpiration slows down as vapour pressure deficit (D) increases which confirms the findings of Dragoni et al. (2005) in apple.

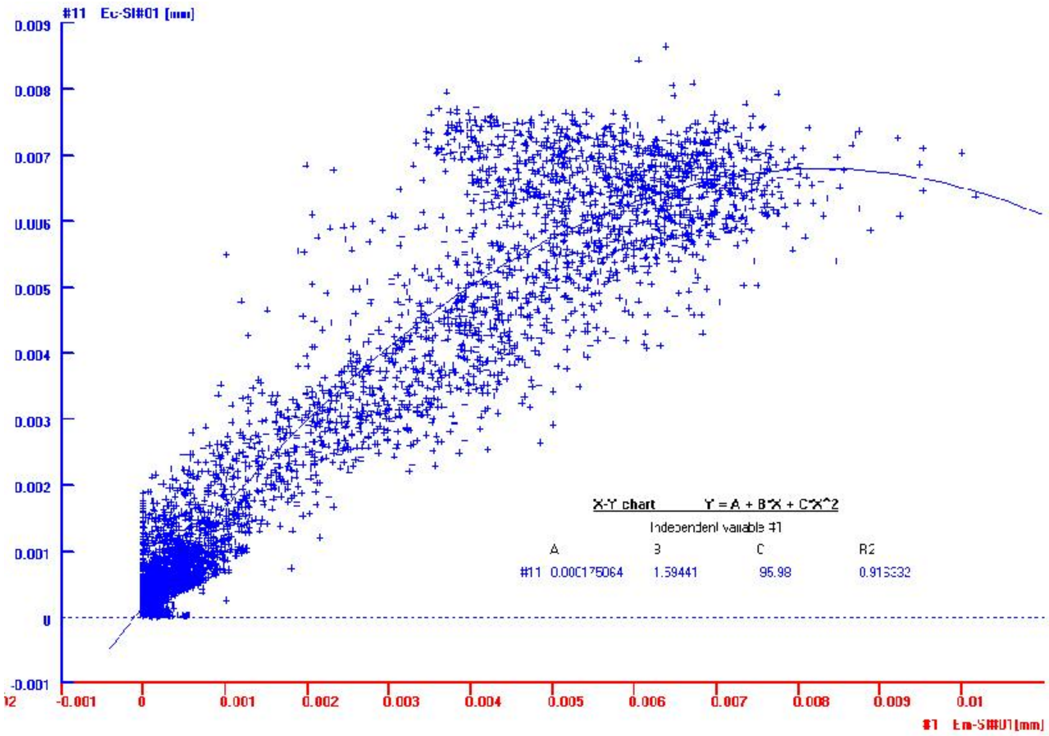

Figure 3. Regression analysis between calculated (modelled) (Ec) and measured (Em) transpiration values for a selected period of measurement. The graphs includes all the measurements, including a considerable zero values shown in the left part of the graph since the diurnal course was used.

Conclusions

We have demonstrated that this transpiration model can predict the actual transpiration of these young apple selections as candidate rootstocks. Rather than identifying the most appropriate rootstock for drought resistance, the main purpose of this paper was to test a transpiration model to be effectively used to screen a large number of genotypes or even seedling from a cross in fruit tree species. Although it was tested on apples, the structure of the model being based on sap flow together with an assessment of intercepted radiation, allow the computation of transpiration in the main fruit tree species under different climates with a degree of precision that should be greater than the standard engineering methodology which uses a single crop coefficient regardless of climate. For the first time in literature, we have shown real–time, dynamic transpiration measurement.

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