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# MONITORING OF THE EVAPOTRANSPIRATION PROCESSES IN RIPARIAN GRASSLANDS

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***Abstract***

*The paper presents the results obtained from monitoring the evapotranspiration processes in riparian grasslands located in Poeni village, Romania near Glavacioc River and the testing of portable instrumentation developed to monitor continuously the potential evapotranspiration (PET). The Penman-Monteith method was selected for the experimental study of PET groundwater dependent ecosystems in the INTER-ASPA project. The microclimate measurements for evapotranspiration assessments were performed between September 14 and 19, 2018. Following the preliminary mapping of the herbaceous vegetation, 12 species of grasses, 5 legumes and 23 species from other botanical families were identified. The PET varied from 0.71 to 1.07 (trees), 0.57 to 0.95 (shrubs), and 0.58 to 1.04 mm day$^{-1}$ (grassland). The 7 days average of the geometrical mean of all vegetated surfaces was 0.86 mm day$^{-1}$, which can be considered a descriptive constant for the Poeni riparian ecosystem for the period of measurements. The PET rates varied significantly especially from wind speed, solar radiation and temperature fluctuations. It was found that grassland canopy had PET rates higher than the taller canopy of shrubs and very close to the tree canopy.*

***Key words**: albedo, biometeorology, floristic composition, Penman-Monteith, Photosynthetically Active Radiation.*

## INTRODUCTION

The hydrology of groundwater and streamflow clearly influences the dynamics of riparian and wetland ecosystems (Grimm et al., 1997) with direct effects on floristic composition. When modelling the flow in such vegetated systems, it is important to accurately quantify the seasonal riparian evapo-transpiration as a critical groundwater boundary condition (Goodrich et al., 2000). The way by which simulation of evapotranspiration (ET) is performed can modify calculated heads and consequently the system dynamics computations (Banta, 2000).

Riparian and wetland ecosystems usually host a substantial number of plant types and species. By using *plant functional groups* and their in-field identification, the complexity of individual species and phytosociological associations may be simplified into a relatively small number of general recurrent patterns (Maddock et al., 2012).

Species biological characteristics such as plant habitus and foliage architecture, and their ecophysiological response to the environmental conditions i.e., density, have key effects on the transpiration rates (Pearson & Ison, 1987). Meinzer et al. (1997) found that large woody plants detain various maximum rooting depths, hydraulic architecture and transpiration rates compared to smaller trees. Moreover, vegetated areas with high densities of herbaceous and woody plants were characterized by higher transpiration rates than scattered spatial arrangements of plant species (Monteith, 1981; Milică et al., 1982).

In Romania, riparian and wetland ecosystems often contain valuable grasslands of different typologies based on predominant grass species such as *Agrostis stolonifera*, *Alopecurus pratensis*, *Poa pratensis*, *Lolium perenne*, *Arrhenatherum elatius*, *Festuca pratensis* etc. depending on altitude. Among the woody species that forms the groves (riparian forests), *Alnus glutinosa* with *Alnus incana* (at higher altitudes), willows (*Salix fragilis* etc.), elms

(*Ulmus minor* etc.), poplars, and other species can be mentioned.

The riparian grasslands are spread over lowlands of riverside, terraces, river valleys and floodplains, but without water excess, on gley and alluvial soils, clay-loamy soils, weakly acidic or poorly alkaline. They are characterized by stable soil cover with vegetation (95-100%) and by the participation of the dominant species *Agrostis stolonifera* with 70%, which is a species with a high fodder value (Motcă et al., 1994). The herbaceous species forming the floristic composition of riparian grasslands generally have shallow root systems. In the mixed canopy of the riparian grasslands, grasses reach usually 40-50%, legumes 20-25%, rather high, and species from other botanical families approximately 25%.

Among all these species, there are plants with no forage value or harmful to the animal products: *Deschampsia caespitosa*, *Potentilla reptans*, *Rumex crispus*, *Mentha aquatica*, *Gratiola officinalis*, *Ranunculus repens*, *Stellaria graminea*, *Juncus effusus*, *Carex hirta* etc. The forage yield of these grasslands is 1.5-3.5 t $ha^{-1}$ DM (7.5-17.5 t $ha^{-1}$ green fodder) and the pastoral value is 1.75-2.75 (based on ground cover) or 35-55 (based on frequency), which falls within the category of intermediate quality grasslands (Motcă et al., 1994). *Agrostis stolonifera* grassland type supports an animal load of 0.7-1.0 LSU $ha^{-1}$ (livestock unit), but because of the increased soil moisture, mowing is recommended. The following terms are related to the riparian evapotranspiration:

**Evaporation and transpiration** are important components of the water circuit in nature that is also important for groundwater dependent ecosystems (GDE). Evaporation is the loss of water in the form of vapours from a wide variety of surfaces, lakes, rivers, bare soil and vegetation (Dinca et al., 2017). Transpiration consists in the loss of water contained in plant tissues and the elimination of produced vapours in the surrounding atmosphere. Plants preponderantly lose water through stomata. Then, evaporation and transpiration occur simultaneously and it is not easy to distinguish between the two processes.

**Potential evapotranspiration** (PET) is the rate at which evapotranspiration can occur from a wide area, fully and evenly covered with vegetation in the growing stage that has unlimited access to soil water resources and without direct effects of the advection or heating processes (Dingman, 2014).

**Evapotranspiration of the reference crop** ($ET_o$) is the evapotranspiration amount specific to a cultivated species that is not limited in terms of water availability. FAO-56 adopts the specific characteristics of the reference crop with a certain height (0.12 m), surface resistance (70 s $m^{-1}$) and albedo (0.23). Then, $ET_o$ is determined using the Penman-Monteith equation (McMahon et al., 2013).

**Actual evapotranspiration** ($ET_a$) is defined as the amount of water transferred as water vapour from the surface of an evaporation surface (surface water, bare soil, vegetation-covered area etc.). The process of evapotranspiration depends on meteorological, edaphic, and plant physiological factors.

In a heterogeneous approach, four groups of factors that influence the magnitude of the ET processes may be considered:

(i) *Meteorological parameters*: net radiation, air temperature, air relative humidity, and wind speed.

(ii) *Factors related to the phytosociological association or the cultivated species*: differences in plant resistance to transpiration or conductivity of the vegetal canopies, height of the canopy, canopy roughness, albedo, and characteristics of the root system.

(iii) *Environmental conditions*: ground cover, plant density and soil water content.

(iv) *Trophic and limiting factors*: macronutrients and pollutants.

ET can be measured directly in the field using instruments such as lysimeters, evaporimeters and eddy covariance systems for measuring the fluxes of energy over a variety of ecosystems (Burba & Anderson, 2005; Goss & Ehlers, 2009; Parisi et al., 2009).

These tools are expensive and difficult to maintain in order to provide point ET measurements, which sometimes are not valid to be applied for larger areas (being spatially limited).

For overcoming these problems, various models for ET assessment were developed depending on the number of variables used e.g., Thornthwaite, Blaney-Criddle, Penman, Penman-Monteith, FAO-56, Priestley-Taylor, FAO-24 Blaney-Criddle, Turc, Hargreaves-Samani, Morton etc. (Allen et al., 1998).

Models for ET estimation range from simple empirical equations to complex models based on radiative-advective balance using synthetic regional indices (e.g., land use/land cover, Leaf Area Index obtained from NDVI – Normalized Difference Vegetation Index, albedo, and FAPAR - Fraction of photosynthetically active radiation) obtained from remote sensing systems (McShane et al., 2017). Most of these models are applicable to the weather and vegetation conditions of a particular region, and the synthetic coefficients that apply to those locations limit their use in other regions (so, they may have a diminished degree of generalization). Then, such models are widely used to estimate ETs coefficients in various area of study followed by their calibration and validation (Goudriaan, 1977).

In a comparative study conducted in Romania using lysimeters, it was found that, according to the meteorological data available in the studied area, several methods i.e., Blaney-Criddle, Penman and Thornthwaite provide acceptable results for estimating $ET_o$. Blaney-Criddle provided 15-20% higher monthly $ET_o$ values compared to the other two methods. The results obtained from Penman and Thornthwaite methods are almost equal ($ET_o$ values supplied by Penman were slightly higher for the first months of the vegetation period, due to the quantification of spring wind characteristics). For Romania, Grumeza and Kleps (2005) recommended the Thornthwaite method because it does not involve the use of laborious calculations and is validated over time. If sufficient meteorological records are available, it is recommended to use the revised Penman method because it better accounts the conjugated effect of climatic factors.

Due to the availability of meteorological data at hydrographical basin scale and specific in-situ instrumentation to monitor the required parameters (inputs in the evapotranspiration algorithms), the Penman-Monteith and the Priestley-Taylor methods were selected for the experimental study of GDE evapotranspiration to be considered in the INTER-ASPA project (PN-III-P1-1.2-PCCDI-2017-0721), titled "*Tools for modelling processes at the interface between water, soil, plants and air in order to promote the sustainable management of groundwater dependent ecosystems and their integrating river basins*", and funded by the Romanian Government.

INTER-ASPA project aims to create an innovation ecosystem designed to support the mono-disciplinary, inter-disciplinary and trans-disciplinary development of research domain related to the interface processes between water, soil, plant and air on several strategic cycles. The project is developed between 2018 and 2020. In the framework of INTER-ASPA, one of the research objectives is the characterization of evapotranspiration processes at hydrographical basin scale for GDE including riparian ecosystems.

The paper presents the preliminary results obtained from monitoring the evapo-transpiration processes in riparian grasslands and the testing of portable instrumentation developed to monitor continuously the PET.

## MATERIALS AND METHODS

As planned in the INTER-ASPA project, field measurements have been prepared to establish an adequate methodology for the determination of evapotranspiration in GDEs. The experimental site, considered relevant from the point of view of the project objectives, was chosen in the Glavacioc River basin (cadastral code: X-1.23.11.8) in the wetland area of Poeni village, Teleorman County, south of Romania.

The Glavacioc River is a tributary of the Câlniştea River having a length of 120 km, a sinuosity coefficient of 1.69 and an average altitude of 118 m. It has a basin of 682 $km^2$, oriented from northeast to southeast, more developed in the upper part. In the Poeni village administrative area, there are forests, agricultural lands and grasslands, but also oil extraction fields. Potential complex GDEs are located in the northwest and southeast of Poeni village.

Figure 1. The study area with riparian and wetland ecosystems located in Poeni, Teleorman County near the Glavacioc River (stereographic coordinates of central point N 322137.52 m; E 527447.87 m)

Figure 2. Instrumentation used for *in situ* monitoring of evapotranspiration at riparian grassland level in Poeni, Teleorman County (beam fraction sensor for PAR monitoring; digital anemometers; microclimate multiparameters; temperature sensors; soil moisture sensors)

Figure 1 presents the study area with riparian and wetland ecosystems located in Poeni, Teleorman County near the Glavacioc River (stereographic coordinates of central point N 322137.52 m; E 527447.87 m measured with a GPS receiver Garmin Oregon 650t).

The microclimate measurements for evapotranspiration assessments were performed between September 14 and 19, 2018 using a PAR monitoring system comprising a beam fraction sensor, 2 digital anemometers, 2 microclimate multi-parameters, air and soil temperature sensors, and soil moisture sensors (Figure 2).

PAR measurements were performed continuously between 11.00 a.m. and 1.00 p.m. at a sampling rate of 10 seconds.

The parameters related to the advective processes (temperature, relative air humidity and soil moisture) were measured discontinuously in 6 points (3 inside, and 3 outside the herbaceous canopy).

The distances between monitoring points were measured with a professional measuring wheel. Albedo (the ratio between reflected and global radiation) was determined with a portable pyranometer for different vegetated surfaces (Figure 3).

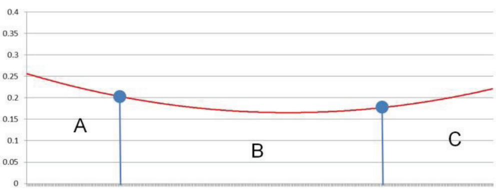


Figure 3. Albedo variations in correlation with the vegetation type (A-*grassland*; B-*trees*; C-*shrubs*)

In parallel with the microclimate measurements, a quick inventory of the floristic composition was performed to assess the plant species existing in the study area.
The data obtained from in-situ monitoring was used in the Penman-Monteith algorithm (Dingman, 2014) requiring the canopy height, the conductance properties of the leaf, the albedo, the LAI, the atmospheric pressure, the incident global radiation, the cloud cover, the air temperature, the relative humidity, the wind speed, and the soil moisture deficit.

$$PET = \frac{1}{\lambda} \frac{\Delta(R_n - g) + \rho_a c_a {(v'_a - v_a)}/{r_a}}{\Delta + \gamma(1 + {r_s}/{r_a})}$$

where: *PET* is Penman-Monteith's potential evapotranspiration; $R_n$ is the daily net incident radiation on the vegetated surface; $g$ is the soil heat flux; $\rho_a$ is the average air density at constant pressure; $c_a$ is the specific air heat; $r_a$ is the aerodynamic resistance; $r_s$ is the surface resistance; $(v'_a - v_a)$ represents the pressure deficit of the air vapours.
*PET* was calculated for three types of vegetated surfaces existing in Poeni riparian ecosystems i.e., trees, grassland and shrubs during the monitoring period (September 14-19, 2018). Leaf conductance properties for riparian ecosystems were retrieved from literature. LAI was assessed using a scanning procedure and area meter recognition by software (Dunea & Moise, 2008). It is expected that in the 2nd phase of the INTER-ASPA project, a porometer for leaf conductance measurements and the Delta-T Devices Sunscan system for LAI will be used for more accurate *in situ* estimations. Table 1 presents the values of inputs used in this paper.

Table 1. Inputs used in the Penman-Monteith algorithm for the estimation of evapotranspiration in Poeni near Glavacioc River (September 14-19, 2018)

| Variable | TREES | SHRUBS | GRASSLAND |
|---|---|---|---|
| Canopy Height (m) | 8 | 1.2 | 0.45 |
| Conductance factor | 0.50 | 0.46 | 0.49 |
| Maximum leaf conductance (mm/s) | 2.30 | 2.16 | 2.20 |
| Albedo | 0.19 | 0.20 | 0.21 |
| LAI ($m^2$ $m^{-2}$) | 3.3 | 2.9 | 2.6 |

## RESULTS AND DISCUSSIONS

The heterogeneous canopies from wetlands and riparian ecosystems are characterized by various rates of solar energy conversion into dry matter, thus various biological efficiencies (light use efficiencies) and implicitly different rates of water use efficiency (McCree, 1973; Campbell, 1986; Sinoquet, 1993; Dunea et al., 2015). For this reason, the main objective of the field experiments planned within the INTER-ASPA project is to establish GDEs-specific evapotranspiration rates and the magnitude of the influence of macronutrients and pollutants on them. Also, the influence on eco-physiological indicators such as the efficiency of radiation use and the efficiency of water use will be also determined. The resulted coefficients will provide useful information for downscaling the information retrieved from the remote sensing systems such as MODIS, Sentinel 2, Landsat 8, and PROBA-V (Dunea et al., 2014).
Following the preliminary mapping of the herbaceous vegetation, 12 species of grasses, 5 legumes and 23 species from other botanical families were identified. In the riparian grassland, several types of heterogeneous canopies have been observed, which requires a unitary approach to characterize the eco-physiological processes influence by the evapotranspiration characteristics.
The perennial grasses accounted for 60-65% having a good ground cover (>80%) with the following species: *Agrostis stolonifera, Alopecurus pratensis, Poa pratensis, Lolium perenne, Agrostis canina, Festuca pratensis, Poa trivialis, Holcus lanatus, Agropyron repens, Poa palustris, Cynodon dactylon, Glyceria maxima. Agrostis stolonifera, Alopecurus pratensis, Poa pratensis, Lolium perenne, Arrhenatherum elatius, Festuca pratensis* etc. The dominant species was the creeping bentgrass *Agrostis stolonifera*, a sod-forming grass used on reclamation sites, lawns and for soil erosion control.
The identified legumes were *Trifolium repens, Trifolium pratense, Medicago lupulina, Galega officinalis, Vicia cracca* etc. having a low participation in the grassland canopy (10-15%).

Figure 4. Riparian grassland at Poeni, Teleorman County near Glavacioc River - *Agrostis stolonifera* type

Species from other botanical families (25-30%) were: *Typha angustifolia* (dominant species especially near river banks), *Taraxacum officinale, Plantago major, Cichorium inthybus, Symphytum officinale, Daucus carota, Leontodon autumnalis, Deschampsia caespitosa, Potentilla reptans, Rumex crispus, Mentha aquatica, Gratiola officinalis, Ranunculus repens, Stellaria graminea, Juncus effusus, Carex hirta, Rosa canina, Tragopogon pratensis, Prunella vulgaris, Glycyrrhiza echinata, Potentilla anserine, Arctium lappa,* and *Bidens tripartite*.

The most frequent woody species grouped in rare groves were: white poplar (*Populus alba*), willows (*Salix fragilis* etc.), elms (*Ulmus minor* etc.) and fruit-growing trees.

Consequently, we have assessed the evapotranspiration for three types of canopies (grassland; shrubs; trees) using the coefficients and values from Tables 1 and 2.

Table 3 shows the PET values provided by the Penman-Monteith algorithm for each day during September 14 and 19 (7 days).

Table 2. Daily averages of the meteorological inputs used in the Penman-Monteith algorithm for the estimation of evapotranspiration of riparian ecosystem in Poeni near Glavacioc River (September 14-19, 2018), altitude 117 m

| Date | Pressure | Radiation | Cloud cover | Air Temp | Rel. Hum. | Wind speed |
|---|---|---|---|---|---|---|
| | kPa | MJ $m^{-2}$ | - | °C | % | m $s^{-1}$ |
| 14.09 | 100.32 | 22 | 0.25 | 21.8 | 0.59 | 1.6 |
| 15.09 | 100.36 | 19 | 0.4 | 23.3 | 0.52 | 2.7 |
| 16.09 | 100.80 | 21 | 0.1 | 21.8 | 0.62 | 2.9 |
| 17.09 | 101.17 | 20 | 0.3 | 20.6 | 0.59 | 3.6 |
| 18.09 | 101.07 | 21 | 0.1 | 20.3 | 0.58 | 2.5 |
| 19.09 | 101.07 | 23 | 0 | 19.3 | 0.55 | 2.8 |
| 20.09 | 100.91 | 24 | 0 | 19.1 | 0.54 | 2.1 |

The PET varied from 0.71 to 1.07 (trees), 0.57 to 0.95 (shrubs) and 0.58 to 1.04 mm $day^{-1}$ (grassland). A rate of 1 mm $day^{-1}$ is equivalent with a loss of 10 $m^3$ $ha^{-1}$ $day^{-1}$. The 7 days average of the geometrical mean of all vegetated surfaces was 0.86 mm $day^{-1}$, which can be considered a descriptive constant for the Poeni riparian ecosystem for the period of measurements. Interestingly, the PET varied significantly especially from wind speed, radiation and temperature fluctuations. Grassland canopy showed PET rates higher than the taller canopy of shrubs including *Typha* species, having the highest variance.

Table 3. Potential evapotranspiration computed with Penman-Monteith algorithm for various vegetated surfaces in Poeni near Glavacioc River

| Date | PET trees | PET shrubs | PET grassland | *Geometrical mean* |
|---|---|---|---|---|
| 14.09 | 0.968 | 0.866 | 0.945 | ***0.92*** |
| 15.09 | 0.707 | 0.569 | 0.58 | ***0.61*** |
| 16.09 | 0.964 | 0.827 | 0.882 | ***0.89*** |
| 17.09 | 0.889 | 0.719 | 0.734 | ***0.78*** |
| 18.09 | 0.883 | 0.839 | 0.891 | ***0.87*** |
| 19.09 | 1.031 | 0.884 | 0.943 | ***0.95*** |
| 20.09 | 1.069 | 0.952 | 1.039 | ***1.02*** |
| ***Mean*** | ***0.93*** | ***0.81*** | ***0.86*** | ***0.86*** |
| *CV%* | *12.85* | *15.67* | *17.89* | *15.48* |
| *Min.* | *0.71* | *0.57* | *0.58* | *0.61* |
| *Max.* | *1.069* | *0.952* | *1.039* | *1.02* |

Concomitantly with the PET measurements, PAR measurements were performed (Figure 5). The average of the PAR during 11.00 a.m. to

1.00 p.m. was 1343.5 µmols $m^{-2}$ $s^{-1}$ (CV = 14.5%), while the diffuse PAR was 250.2 µmols $m^{-2}$ $s^{-1}$ (CV = 6.2%). Regarding the albedo of riparian grassland, the overall average was 0.19, which is in line with other reported values for wetlands and riparian grasslands (Geiger, 1965; Baumgardner et al., 1985; Kotoda, 1986).

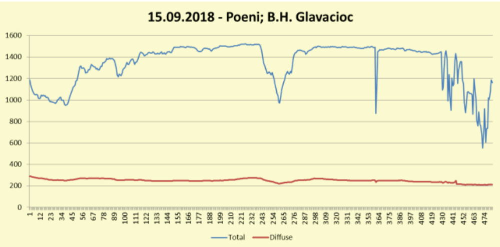


Figure 5. Example of PAR (µmols $m^{-2}$ $s^{-1}$) measured from 11.00 a.m. to 1.00 p.m. in Poeni riparian grasslands

Following the monitoring campaign performed in Poeni riparian grasslands, it was concluded that continuous monitoring of PET would be more useful to understand the diurnal-nocturnal cycles of ET. To achieve this goal, the continuous monitoring has been started in the riparian grasslands of Ialomita River, Romania (Figure 6), by deploying a portable PET system based on adequate sensors interfaced on the Delta-T Devices GP2 data logger that uses the DeltaLINK 3.8 software, which is able to provide hourly calculations of PET based on Penman-Monteith algorithm(https://www.delta-t.co.uk/software/deltalink/).

The system has been tested to obtain hourly time series of PET that will be used to extract/validate useful key figures from remote sensing information.

## CONCLUSIONS

The current study allowed the development of the methodological background to monitor evapotranspiration processes that occur in riparian grasslands. It is expected that the methodological approach will provide sustainable results also for cash crops monitoring for harvest index forecasting (Ion et al., 2015) and for characterization of the crop-weed interactions (Spitters & Aerts, 1983).

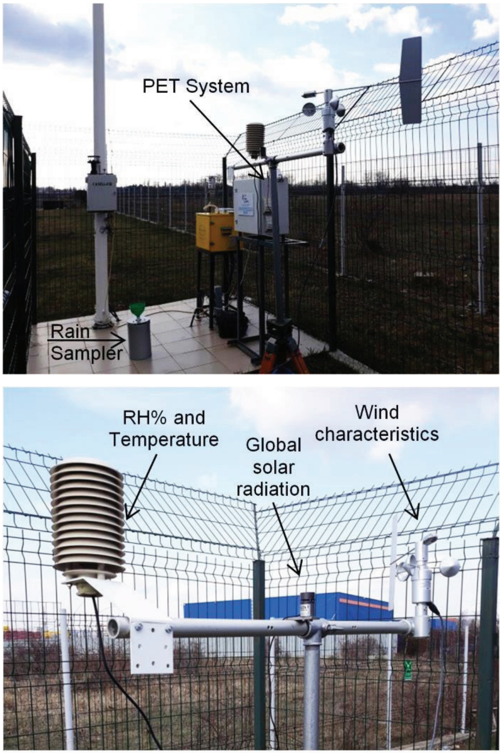


Figure 6. The PET continuous monitoring system deployed in the monitoring platform of the Department of Environmental Engineering - Valahia University of Targoviste, for assessing the canopy characteristics of riparian grasslands from Ialomita River, Romania

It was found that grassland canopy had PET rates higher than the taller canopy of shrubs and very close to the tree canopy. Since PET estimations are important for modelling hydrological processes and for groundwater evapotranspiration assessment, the presented methodology will be further refined in new monitoring campaigns in various riparian grasslands.

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