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# AN ASSESSMENT OF THE WATER USE EFFICIENCY IN ALFALFA CANOPY UNDER THE CLIMATE REGIME OF TARGOVISTE PIEDMONT PLAIN

**Niculae DINCĂ[1], Daniel DUNEA[2], Stefano CASADEI[3], Nicolae PETRESCU[2], Sebastian BARBU[1]**

[1]University of Agronomic Sciences and Veterinary Medicine of Bucharest, 59 Marasti Blvd, District 1, Bucharest, Romania
[2]Valahia University of Targoviste, Campus, Aleea Sinaia no.13, RO-130004, Targoviste, Romania
[3]Universita degli Studi di Perugia, Borgo XX Giugno, 74, Perugia, Italia

Corresponding author email: dan.dunea@valahia.ro

***Abstract***

*The rationale of the overall experiment was to emphasize the ecophysiological behavior of alfalfa in the eco-climatic conditions of Targoviste Piedmont Plain, from the south of Romania, during three contrasting years of cropping (2012-2014) from the rainfall point of view. Potential evapotranspiration (PET) is a complex index that describes the conceptual processes of soil water losses in atmosphere through evaporation and transpiration from the canopies depending on the plant species, land cover, climatic conditions, and soil type. Reference ET from a defined vegetated surface is a function of local weather serving as an evaporative index by which specialists can predict ET for a wide range of vegetation and surface conditions using the application of "crop" coefficients for agricultural or landscaped areas. The objectives of the study were to establish the water use (ETc) and water use efficiency (WUE) of alfalfa for the specific conditions of Targoviste Piedmont Plain, Romania, and to quantify the effects of limiting water on the growth and development of alfalfa tested cultivars. Roxana and Mihaela cultivars of alfalfa (Medicago sativa L.) developed by NARDI Fundulea were sown in a Latin rectangle design with four replicates. Both cultivars showed valuable biological characteristics regarding the WUE in non-irrigated conditions i.e., annual average of WUE of 13.4 kg DM mm$^{-1}$ ha$^{-1}$ (1$^{st}$ year of cropping), 14.7 (2$^{nd}$ year) and 18.4 (3$^{rd}$ year) in Roxana cultivar, and 13.6 kg DM mm$^{-1}$ ha$^{-1}$ (1$^{st}$ year of cropping), 16.1 (2$^{nd}$ year) and 19.1 (3$^{rd}$ year) in Mihaela cultivar, respectively. The significant increasing of WUE in the last year of cropping was correlated with a well-distributed rainfall regime during the vegetation season and increased annual quantity (>1000 mm). No significant differences ($p<0.05$) were found in yield and WUE among varieties and between cropping years. The results can be used to estimate the economic impact of irrigation use, water consumption and optimal scheduling in alfalfa cropping systems.*

***Key words***: *evapotranspiration, reference evapotranspiration, ASCE modified Penman-Monteith algorithm, dry matter.*

## INTRODUCTION

Ecological factors play an important role in the growth and development of alfalfa (*Medicago sativa* L.) plants. Alfalfa has a wide ecological plasticity, but its productive potential can be reached only under certain soil and climatic conditions. It is a C3 perennial legume with a high water use.

Because of its deep and well-developed root system, alfalfa has an increased resistance to drought, despite the fact that consumes significant quantities of water to accumulate dry matter. In Romania, the highest yields are recorded in areas with annual rainfall of 500-650 mm, which are well distributed during the growing season (Motcă, 2005). Alfalfa does not support the water puddles on the surface and any excess of water in the soil. The stagnation of water, for 3-9 days, immediately after mowing, has determined the mass reduction of the root system by 30-80%, respectively the production by 20-60% (Moga et al., 1996). On the lands where the ground water table is at a depth of less than 1.2 to 1.5 m, the root growth and the activity of nitrogen-fixing bacteria are intensively hindered reducing the vitality and production of alfalfa.

Requirements for heat and light are large in alfalfa. The amount of temperature for alfalfa plants required to reach the start of flowering in the 2$^{nd}$ and 3$^{rd}$ year of vegetation is around

900°C for the first cutting cycle and about 800-850°C for the next two cuttings (Motcă, 2005). Brown et al. (2006) found that the estimated radiation use efficiency (RUE) in alfalfa showed a clear seasonal pattern, increasing from 0.80 g DM $MJ^{-1}$ in early spring to 1.60 g DM $MJ^{-1}$ in late summer before decreasing to 0.80 g DM $MJ^{-1}$ in late autumn.

The rationale of the study was to emphasize the ecophysiological behavior of alfalfa in the eco-climatic conditions of Targoviste Piedmont plain, from the south of Romania, during three contrasting years of cropping. The concept of reference evapotranspiration (ET) was developed in the 1970's as a practical and definable replacement for the concept of potential evapotranspiration (PET) (Allen et al., 2004). PET is a complex index that describes the conceptual processes of soil water losses in atmosphere through evaporation and transpiration from the canopies depending on the plant species, land cover, climatic conditions, and soil characteristics (Dunea and Dincă, 2015).

Reference ET, which is a function of local weather, represents the ET from a defined vegetated surface, and serves as an evaporative index by which specialists can predict ET for a range of vegetation and surface conditions using the application of "crop" coefficients for agricultural or landscaped areas (Allen et al., 2004).

The Penman-Monteith equation identifies the key abiotic and biotic factors that control canopy evaporation (Jarvis and McNaughton, 1986).

In this context, the objectives of the study were to establish the water use (ETc) and water use efficiency (WUE) of alfalfa for the specific conditions of Targoviste Piedmont Plain, Romania, and to quantify the effects of limiting water on the growth and development of alfalfa tested cultivars. The results can be used to estimate the economic impact of irrigation use and optimal scheduling in intensive alfalfa cropping systems.

## MATERIALS AND METHODS

Experiments were carried out between 2012 and 2014 in Targoviste Piedmont Plain, Romania at Dobra village (N44°46¹.905, E25°43¹.045, 179-m altitude) on pseudogleic brown alluvial soil. Roxana and Mihaela cultivars of alfalfa (*Medicago sativa* L.) were sown in a Latin rectangle design with four replicates. Both cultivars having valuable biological characteristics were developed by NARDI Fundulea (Schitea, 2010). The synthetic cultivars were obtained from the recombination of foreign and Romanian germplasm, presenting rapid spring growth, faster regrowth after cutting, good resistance to common diseases occurring in Romania, and improved winter hardiness.

The plots were sown in pure stand in March 22, 2012. The plants were given nitrogen fertilizer in all experimental variants at one rate (25 kg N $ha^{-1}$) to avoid nutrient limiting growth. Irrigation was not applied to comply with the common cropping practices used by farmers. Three cutting cycles were performed each year according to the recommended phenophases for alfalfa harvesting (Moga et al., 1996) i.e., 1st cutting cycle: at the beginning of flowering stage; 2nd: +7 weeks from the 1st cut; 3rd cutting: +6 weeks after 2nd cutting.

Samples were collected before each cutting cycle using a quadrate of 50×50 cm in two points of each variant and each repetition to determine dry matter accumulation (g $m^{-2}$). Samples were dried in an oven at 70°C for 24 hours. The dry matter was determined using a Sartorius precision balance, and the results were extrapolated to a full hectare.

Evapotranspiration (ET) represents the sum of evaporative losses of water from the soil surface – evaporation process, and from the canopy – transpiration process (Allen et al., 1998; Dunea et al., 2014).

A series of equations were used to establish alfalfa's water use (ETc) and water use efficiency (WUE) for conditions of the Targoviste Piedmont Plain, Romania. The reference evapotranspiration for short canopies (ETo) using required weather data was calculated based on the standardized Penman-Monteith algorithm modified by the Environmental Water Resources Institute (EWRI) of the American Society of Civil Engineers – ASCE (see Allen et al., 2004).

The outputs of the model were the daily mean of ETo for each month. The input variables in the algorithm required a series of weather measurements that comply with the complexity of the equations, the estimation period, and the accuracy of results e.g., solar radiation, temperature regime, relative humidity and wind speed.

Table 1 summarizes the statistics of meteorological time series recorded between 2012 and 2014.

Table 1. The meteorological variables recorded in Targoviste Piedmont Plain between 2012 and 2014 – annual data

| Variable | 2012 | 2013 | 2014 |
|---|---|---|---|
| *Temperature* (°C) | - | - | - |
| Average | 10.9 | 8.1 | 10.8 |
| Min. | -23.7 | -14.9 | -17.5 |
| Max. | 39.3 | 32.7 | 33.1 |
| St.dev. | 11.6 | 8.9 | 9.0 |
| Coeff. of Var. (%) | 105.7 | 108.9 | 83.2 |
| *Atmospheric pressure* (mm Hg) | - | - | - |
| Average | 735.5 | 735.4 | 735.8 |
| Min. | 717.7 | 712.2 | 722.8 |
| Max. | 749.6 | 752.3 | 752.2 |
| St.dev. | 5.5 | 20.1 | 4.6 |
| Coeff. of Var. (%) | 0.8 | 2.7 | 0.6 |
| *Relative humidity* (mm) | - | - | - |
| Average | 71.4 | 78.3 | 79.8 |
| Min. | 15.0 | 22.0 | 14.0 |
| Max. | 100.0 | 100.0 | 100.0 |
| St.dev. | 22.3 | 19.4 | 19.4 |
| Coeff. of Var. (%) | 31.3 | 24.8 | 24.3 |
| *Dew Point* (°C) | - | - | - |
| Average | 4.9 | 3.9 | 6.8 |
| Min. | -25.8 | -16.6 | -19.0 |
| Max. | 20.3 | 22.2 | 21.7 |
| St.dev. | 9.1 | 7.3 | 7.2 |
| Coeff. of Var. (%) | 187.6 | 184.4 | 106.6 |
| *Precipitations* (mm) | - | - | - |
| Average (mm/day) | 2.0 | 2.0 | 2.1 |
| Min. (mm/day) | 0.1 | 0.1 | 0.1 |
| Max. (mm/day) | 27.0 | 29.0 | 29.0 |
| St.dev. | 3.4 | 3.3 | 3.4 |
| Coeff. of Var. (%) | 174.5 | 162.3 | 159.5 |
| *Sum of precipitations* (mm) | 612 | 553 | 1039 |
| *Days without precipitations* | 308 | 235 | 300 |
| *Mean Wind Speed (m/s)* | - | - | - |
| *Average* | 2.5 | 2.3 | 2.4 |
| *Min.* | 0.0 | 0.0 | 0.0 |
| *Max.* | 12.0 | 9.0 | 10.0 |
| *St.dev.* | 1.9 | 1.7 | 1.3 |
| *Coeff. of Var. (%)* | 75.4 | 73.1 | 56.2 |

During experiment, the year 2013 recorded the lowest annual average temperature (8.1°C) compared to 2012 and 2014 with more than 2.5°C lower.

The year 2012 showed the highest amplitude of temperature regime, while year 2014 was characterized by the highest amount of annual precipitations.

Crop evapotranspiration (ETc), which is an indicator of the crop water use, provides the evapotranspiration quantum from well-watered fields that achieve full production under the specific climatic conditions (eq. 1).

$$ET_c = K_c \times ET_o \qquad (1)$$

where $K_c$ is a crop coefficient; value of 0.85 was selected for calculating ETc in alfalfa (Allen and Wright, 2002) for each cutting cycle.

The results were used to compute Water Use Efficiency (WUE). WUE is the Ratio between the net yield and the amount of water used to produce that yield (eq. 2).

$$WUE = DM/ET_c \qquad (2)$$

Descriptive, associative, and comparative statistics of the data set was analyzed using SPSS software (SPSS Inc., Chicago, IL, 2011). The computation of multiple range tests (LSD test) provided the statistical significance of comparisons between years, cutting cycles, and cultivars.

## RESULTS AND DISCUSSIONS

The accumulation of aboveground dry matter was constant between the two tested cultivars without significant differences ($p > 0.05$).

Table 2. Dry matter yields (t ha$^{-1}$) of alfalfa cultivars grown in Targoviste Piedmont Plain between 2012 and 2014 (three cutting cycles/year)

| Variety | 2012 | 2013 | 2014 |
|---|---|---|---|
| ***Roxana*** | - | - | - |
| 1st cuting | 3.1 | 3.2 | 3.8 |
| 2nd cuting | 1.8 | 1.9 | 3.3 |
| 3rd cuting | 2.9 | 2.5 | 3.1 |
| Annual yield | **7.8** | **7.6** | **10.2** |
| ***Mihaela*** | - | - | - |
| 1st cuting | 3.3 | 3.5 | 4.0 |
| 2nd cuting | 2.0 | 2.1 | 3.4 |
| 3rd cuting | 2.7 | 2.7 | 3.2 |
| Annual yield | **8.0** | **8.3** | **10.6** |
| LSD 95% | ±1.5 | ±1.5 | ±0.8 |

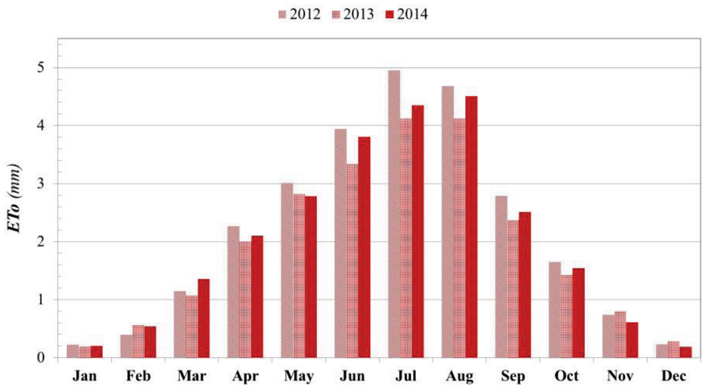


Figure 1. Estimated daily potential evapotranspiration for short canopies (*ETo*) in *mm* under the given climatic conditions of Targoviste Piedmont Plain between 2012 and 2014

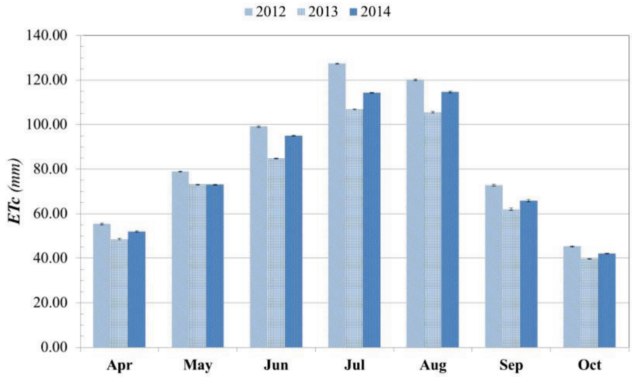


Figure 2. Crop evapotranspiration (*ETc*) in *mm* showing the crop water use under the given climatic conditions of vegetation seasons in Targoviste Piedmont Plain between 2012 and 2014; data were obtained using for alfalfa a crop coefficient (*Kc*) of 0.85 suitable for non-irrigated conditions; error bars represent the standard deviation

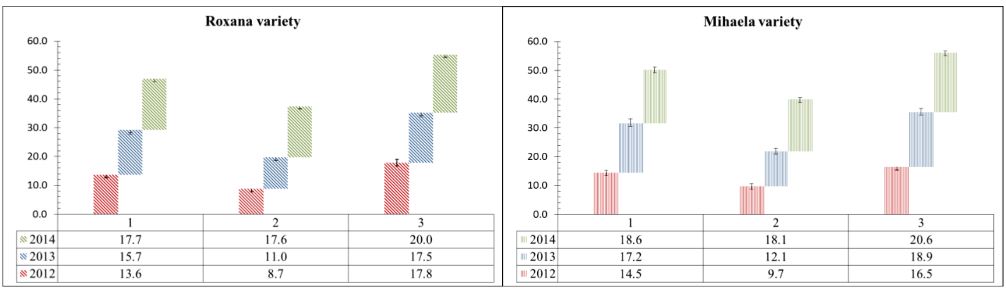


Figure 3. Water use efficiency (*WUE*) of alfalfa cultivars in $kg \cdot mm^{-1} \cdot ha^{-1}$ for each cutting cycle (1-3) in Targoviste Piedmont Plain between 2012 and 2014; data were obtained by dividing the accumulated dry matter by water used during the cropping cycle (*ETc*) ; error bars represent the difference determined between cultivars (no statistical significance $p > 0.05$)

Table 2 presents the dry matter yields (t $ha^{-1}$) of alfalfa cultivars grown in Targoviste Piedmont Plain between 2012 and 2014, for each cutting cycle. The results are in agreement to the yields reported by Motcă (2005) obtained at Moara Domneasca in Romanian Plain between 2002 and 2004 in non-irrigated and non-fertilized conditions (i.e., average of three cropping years ranging between 8 and 9 t DM $ha^{-1}$).

Schitea (2010) reported for Romanian alfalfa cultivars an average production of more than 17 t DM $ha^{-1}$ of the three cropping years in irrigated conditions and application of optimal fertilization. Alfalfa yields were found to be responsive to irrigation level, decreasing with reductions in irrigation amount.

Hansen (2008) reported average yields of 8.4, 7.2, 6.8, and 5.3 t $ac^{-1}$ for 4 treatments i.e., "Full Irrigation", "Stop irrigation after 2nd cutting", "Spring and fall irrigation", and "Stop irrigation after 1st cutting", respectively, over two years of the study (with 2006 being a dry year and 2007 being a normal year in terms of precipitation).

Conversion of the reported values from acres to hectares provides the following yields: 20.7, 17.7, 16.8 and 13.8 t $ha^{-1}$ respectively. However, in 2006, a dry year, the reported production for the "Stop irrigation after 1st cutting" treatment was 8.8 t $ha^{-1}$, which is close to our findings in rainfed conditions.

In dry land regions, alfalfa yields in non-irrigated conditions varied between 2.3 and 4.7 t $ha^{-1}$ (Chedjerat et al., 2016). Karagic et al. (2005) pointed out that the climatic conditions of the cultivation region have a significant effect on the alfalfa yield, which ranged from 5.4 to 8.9 t $ha^{-1}$.

In this context, optimization of water consumption in forage farms has important implycations for the economic and environmental sustainability of agricultural sector. In our experiment, we followed the common cropping practices used in the region, i.e., an extensive system without major inputs of fertilizers and no irrigation. Such system provides an eco-friendly approach by excluding increased water consumption and associated required energy. However, the obtained yields are almost half compared to full irrigated crops. In the last period, there is a growing interest regarding the application of limited irrigation in cropping systems as a means of addressing changing water supply and demand issues while maintaining profitable irrigated agricultural systems (Hansen, 2008). The quest is on to find the "weak" points in the vegetation season in which to control the crop water stress for avoiding economic losses and a reliable balance between input costs and water consumption especially in areas with high water demands and few water sources. The new cropping practices should consider also the intercropping and mixed cropping as means to increase land utilization e.g., the use of intensive grass-legume mixtures in forage production systems (Dunea and Dincă, 2014). The sowing of two or more species in mixtures would provide benefits regarding the complementary requirements for water, light and nutrients (Dunea and Dincă, 2015; Stanciu et al., 2016). The ecophysiological processes occurring in the forage systems can be assessed using adapted crop growth models (Dunea et al., 2016) or complex hydrological models (Neitsch et al., 2011). WUE is an important variable required to build such models and it can be established in field experiments.

In our experiment, we found that the multiannual climatic variability influencing the estimated daily potential evapo-transpiration and crop evapotranspiration (*ETc*) has a significant correlation with the WUE of both alfalfa varieties (Figures 1 and 2).

Both Romanian cultivars showed valuable biological characteristics in rainfed conditions regarding the WUE i.e., annual average of WUE of 13.4 kg DM $mm^{-1}$ $ha^{-1}$ (1st year of cropping), 14.7 (2nd year) and 18.4 (3rd year) in Roxana cultivar, and 13.6 kg DM $mm^{-1}$ $ha^{-1}$ (1st year of cropping), 16.1 ($2^{nd}$ year) and 19.1 ($3^{rd}$ year) in Mihaela cultivar, respectively (Figure 3).

The increasing of WUE in the last year of cropping was correlated with a well-distributed rainfall regime during the vegetation season and increased annual quantity (>1000 mm). No significant differences ($p < 0.05$) were found in yield and WUE among varieties and between cropping years. The second cropping cycle located during the summer, presented the lowest WUE values in each year. Undersander (1987) reported that the first and fourth cuttings had higher WUE than the middle two cuttings, alfalfa loosing efficiency during the hotter summer cuttings. In 2014, the highest WUE values were recorded because of the rainfall regime.

The lowest values were occurring in 2013, which was the driest year. Hansen (2008) reported values of 0.185 tons $ac^{-1}$ $in^{-1}$ for both years, which converted represents approximately 17.9 kg DM $mm^{-1}$ $ha^{-1}$, which matches positively with the values found in the literature and in our study.

## CONCLUSIONS

The resulted elements characterizing the water use efficiency in alfalfa, which were determined during three vegetation seasons in two Romanian cultivars, are useful for the parameterization of alfalfa growth and development in suitable crop growth models.

Furthermore, the results can be used for defining experiments and future strategies to reduce consumptive water use of alfalfa and to facilitate the estimation of the economic impact of irrigation use and optimal scheduling in alfalfa cropping systems by knowing the moments of crop water stress and the biological potential of the tested cultivars in non-irrigated conditions.

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