INFRASTRUKTURA I EKOLOGIA TERENÓW WIEJSKICH
INFRASTRUCTURE AND ECOLOGY OF RURAL AREAS

Nr IV/3/2015, POLSKA AKADEMIA NAUK, Oddział w Krakowie, s. 1275–1283
Komisja Technicznej Infrastruktury Wsi

DOI: http://dx.medra.org/10.14597/infraeco.2015.4.3.092

EFFICIENCY OF UTILIZATION OF WATER FOR EVAPOTRANSPIRATION OF MOUNTAIN GRASSLANDS

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Summary

The work presents the data on the productive efficiency of water used for evapotranspiration by the sward of mountain grasslands. Mean grassland water productive efficiency for the vegetation period in the Małe Pieniny Mts. region fluctuates from 14.1 to 33.4 $kg \cdot ha^{-1} \cdot mm^{-1}$. The efficiency of water use under the discussed conditions is significantly influenced the amount of produced yield. Water was the least efficiently used by low-yielding sward. Water was the least effectively utilized by the low-yielding sward. Efficiency of water utilization by grasslands is growing with increasing yielding. Maintaining constant ground water level in the meadow habitats at the depth of 0.6m in the Pieniny region leads to a decrease in productive efficiency of water used for real evapotranspiration.

Key words: grasslands, efficiency of water utilization

INTRODUCTION

Vegetation uses water in the transpiration process coupled with photosynthesis. Water requirements of plants are expressed by means of a transpiration coefficient which is defined as the amount of water necessary to produce a unit of plant mass (Roguski and Gabrych 1990). Obviously, transpiration coefficient is diversified for various plant species and different habitat conditions (Roguski *et al.* 1986, Roguski *et al.* 1990, Xeu *et al.* 2008, Clifton-Brown and Lewandowski 2001).

According to FAO data, currently about 70% of fresh water used on the Earth is attributed to agriculture. Therefore, meeting the water requirements of crops, including a possibly high efficiency of its utilization is a major problem. Another grave problem in current plant production is the availability and price of water. Better utilization of water in agriculture is therefore another live issue because of irregularly distributed rainwater, which enforces to take up activities to increase its utilization efficiency coefficient in conversion to agricultural yield (Bouman and Tuong 2001, Liang *et al.* 2006, Zoebl, 2006, Zwart *et al.* 2004)

The value of groundwater feeding by waters draining beyond range of the crops root system is determined by the degree of its utilization in the process of green mass production. The better the water productive efficiency, the lower water amounts are used to obtain the same yields, whereas its excess unused by plants may reinforce soil retention or groundwater. Identification of agents determining water productive efficiency allows for the grassland management, which positively affects water management in the agricultural catchment in the areas of intensive relief.

The work aims to assess the efficiency of water used by mountain grasslands for real evapotranspiration. It was assumed that is depends among others on the land use, the season of the year and occurrence of groundwater.

MATERIAL AND METHODS

The productive efficiency of water used for evapotranspiration on mountain grasslands was determined on the basis of results of lysimetric tests conducted in 1978-2000 at the lyzimetric-meteorological station located at the Research Station of Institute of Technology and Life Sciences in Jaworki near Szczawnica. Measurements of atmospheric precipitations, amounts of water drained from the soil profile and changes of retention in lysimeters were conducted during the vegetation period at decade intervals. The obtained results allowed to determine the real evapotranspiration of variously used grassland sward. Measurements of the amount of yield obtained from the analysed grasslands were also conducted.

The optimisation of water use for production of grassland communities was assessed on the basis of the water productive efficiency (*EPW*) criterion, which is the ratio of the obtained yield (Q) $[kg \cdot ha^{-1}]$ to the amount of water used for efficient evapotranspiration (*ETr*) [mm]. It determines the dry mass yield per water unit used in evapotranspiration process (Dzieżyc 1989, Łabędzki 1997, Terrasson *et al.* 2009) and is expressed by the following formula

$$EPW = Q \cdot ETr^{-1} \; [kg \cdot ha^{-1} \cdot mm^{-1}].$$

The significance of water use efficiency by mountain grasslands was determined basing on the analysis of variance computed on the basis of Student-Newman-Keuls multiple comparison test and Honestly Significant Difference (HSD), calculated by means of Tukey's widest confidence interval test (Ozga-Zielińska and Nawalany 1979).

RESULTS AND DISCUSSION

The conditions characteristic for the Pieniny Mts. Region are favourable for grassland development. Average annual air temperature in the Jaworki area for the 1960-2000 multi-annual period was +6.1°C, and for the vegetation period (April-September) – +12.2°C. The warmest month is July and coldest is January. The vegetation period lasts for 202 days and the period of the most active plant development (temperature over +10°C) – 142 days. The average precipitation [snowfall occurred?] during the vegetation period is 602.2 mm and makes up 67.9% of the annual total (886.5 mm) fluctuating within the range from 407.0 to 933.1 mm. The number of days with precipitation during vegetation period is about 90. June and July are months with the highest rainfall.

Relative air humidity in the vegetation season remains between 73% and 87%. The lowest mean air humidity occurs at the beginning of the vegetation season (April) and the highest in September (Misztal 1996, Twardy and Kuźniar 2002).

Average total reference evaporation computed according to Penman formula in French modification reached 558.4 mm (Misztal 2000), during the vegetation period, which according to the potential evaporation zones identified by Olechnowicz-Bobrowska (1978), places the region of Jaworki on the boundary of the low and moderate reference evapotranspiration.

Average water productive efficiency determined for the Pieniny region during the vegetation season was diversified (Table 1). It fluctuated from 14.1 $kg \cdot ha^{-1} \cdot mm^{-1}$ on the unfertilized meadow without groundwater to 33.4 $kg \cdot ha^{-1} \cdot mm^{-1}$ on the meadow fertilized with the dose of 360 $kg \cdot ha^{-1}$ N, and was greatly similar to the values stated by Łabędzki (1997) for the region of Bydgoszcz (from 12.2 to 37.1 $kg \cdot ha^{-1} \cdot mm^{-1}$) and by Feddes (1985), who obtained the values of water productive efficiency within the interval from 20 $kg \cdot ha^{-1} \cdot mm^{-1}$ at fertilization between 24 to 250 $kg \cdot ha^{-1}$ to 40 $kg \cdot ha^{-1} \cdot mm^{-1}$ at fertilization over 250 $kg \cdot ha^{-1}$.

On the basis of the analysis of variance conducted for average values of water use efficiency by grasslands, it may be stated that it depends significantly ($\alpha = 0.01$) on the kind of grassland (Table 2). A three-cut meadow revealed a thrice higher efficiency of water use than a pasture, whereas the lowest was registered for the sward with constant height of 12-15 cm, managed by its cutting at decade intervals. This confirms significant diversification of water productive efficiency caused by different yielding of variously managed sward and applied nitrogen fertilization. The lowest yield mass per 1 mm of water used for evapotranspiration process characterized low yielding, unfertilized meadow.

Table 1. Water productive efficiency *EWP*

Utilities		Ground water [m]	Fertilization N [$kg \cdot ha^{-1}$]	*EPW* [$kg \cdot ha^{-1} \cdot mm^{-1}$] Cut			Total
				I	II	III	
Meadow	A	–	–	27.2	11.0	6.8	14.1
Meadow	B	–	120	39.4	14.4	12.1	20.2
Meadow	C	–	240	46.3	21.5	12.8	25.7
Meadow	D	–	360	56.9	29.5	27.4	33.4
Meadow	E	0.6	120	36.7	13.5	10.3	19.9
Meadow	F	0.6	240	48.2	15.8	10.5	24.3
Meadow	G	0.6	360	46.2	16.4	8.7	28.8
Pasture	J	–	360	39.7	26.8	30.7	31.9
Sward (12-15 cm)	K	–	120	28.0	11.3	11.6	15.8
Sward (12-15 cm)	L	0.6	120	29.3	13.5	11.7	18.1
$CIR_{0.05}$				3.82	2.08	1.79	2.64

Explantations: $CIR_{0.05}$ – totally significant difference, computed using Tukey's test (for the significance level $\alpha = 0.05$)

Both on the meadow and pasture, water productive efficiency is also greatly diversified during the vegetation season. Water was most efficiently utilized during the first cut (about 57 $kg \cdot ha^{-1} \cdot mm^{-1}$ on the meadow without groundwater and 40 $kg \cdot ha^{-1} \cdot mm^{-1}$ on the pasture without groundwater). In the second and third cut water productive efficiency on the meadow ranged from 6.89 to 29.5 $kg \cdot ha^{-1} \cdot mm^{-1}$, whereas on the pasture it fluctuates from 26.8 to 30.7 $kg \cdot ha^{-1} \cdot mm^{-1}$. Such significant differences in water productive efficiency in individual cuts evidence a higher evapotranspiration relationship of grass on yielding in the first cut and greater influence of climatic factors on *ETr* value in the second and third cuts. Considerable water productive efficiency in the first cut results both from an advantageous arrangement of meteorological factors over that period and the development rhythm of grass vegetation causing the most intensive increment of meadow and pasture sward plant biomass during the spring period. Low air temperatures and its high humidity during the first cut growing limited non-productive evaporation, contributing to high water productive efficiency in this period. This was confirmed also by the research of Ziembińska *et al.* (2004).

Table 2. Significance of differences between selected variants water productive efficiency (*EWP*) determined on the basis of Student-Newman-Keuls test

Research factor	Variants	*EPW* [kg× ha^{-1}×mm^{-1}]
Yielding	A–B	**
	A–C	**
	A–D	**
	E–F	**
	E–G	**
	D–J	*
Utilities	B–K	**
	E–L	*
	B–E	n. i.
Ground water level	C–F	n. i.
	D–G	**
	B–K	**
	K–L	**

Explantations: n.i. – non-significant differences; * – differences significant at $\alpha = 0.05$;
** – differences significant at $\alpha = 0.01$

Water productive efficiency in the investigated region is also affected by the presence of groundwater (Fig.1 and 2). The stable groundwater level on the meadow maintained at the depth of 0.6 m caused a decrease in water productive efficiency by between 7 and 28%. It is compliant with observed lack of a significant effect of maintaining the stable groundwater level on the increase in yield at simultaneously growing amount of water used in the evapotranspiration process by the meadow fed in result of groundwater seepage. Piekut (1997) and Żarski *et al.* (2013) obtained similar results in their experiments conducted in Warsaw-Ursynów.

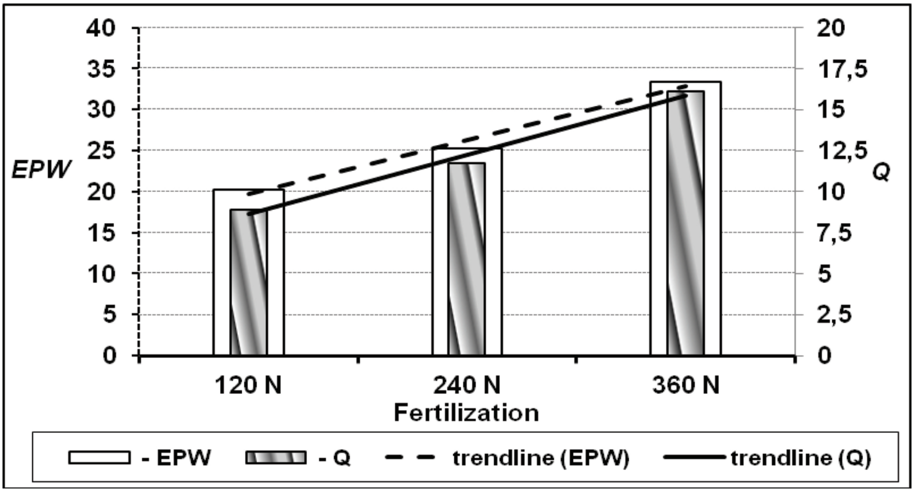

Figure 1. Annual yield (*Q*) and water productive efficiency (*EWP*) of variously fertilized three cut meadow without groundwater

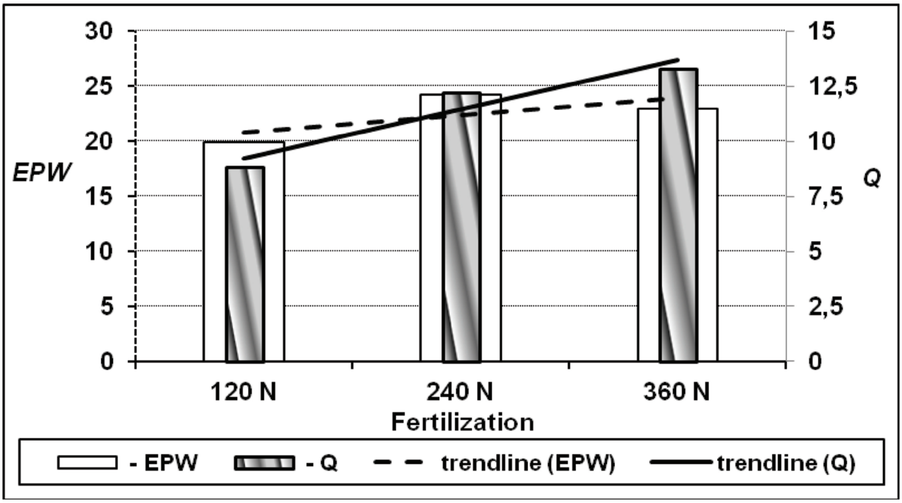

Figure 2. Annual yield (*Q*) and water productive efficiency (*EWP*) of variously fertilized three cut meadow with groundwater on the level of 0.6 m

CONCLUSIONS

In-depth analysis of the results presented in the paper allows to formulate the following conclusions:

1. Water productive efficiency is to a considerable degree dependant on the yielding of meadow-pasture sward. The lowest efficiency of water use characterizes unfertilized, low yielding grassland communities. Highly productive grasslands reveal high efficiency of water use for biomass production.
2. Efficiency of water use in the process of biomass production is significantly diversified during the vegetation period. Water is most efficiently used by grasslands in spring (during the first cut growth). In the second and third cuts productive efficiency decreases considerably.
3. Maintaining a stabilized groundwater level increasing the moisture of meadow habitat soils contributes to a decrease in the efficiency of water use by grassland sward.
4. A greater attention should be paid to agrotechnological measures inclining the plant metabolism to more frugal management of water used for actual evapotranspiration and finally contributing to its more efficient utilization.

ACKNOWLEDGMENTS

The research was realized within the Project no. DS-3337/KEKiOP/2014, financed from the research grant allocated by the Ministry of Science and Higher Education

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Received: 17.07.2015.
Accepted: 06.12.2015