The effect of rainfall and extensive use of grasslands on water regime

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ABSTRACT

Water regimes of extensively used grasslands (one cut per year, two cuts per year, no cut, mulching) were determined and compared by drainage lysimeters in 1998–2000. Although the botanical composition and yields of experimental swards were different, there was no statistically significant difference in their water regime (only the soil moisture content of no-cut variant was significantly higher than in other variants). A determinant factor for the water regime of grasslands (GR) is the sum of rainfall over the growing season while the GR water regime is influenced by land use immediately after the cut. Water runoff from the soil profile 0.0–0.60 m (water supply to the groundwater level) was found to be negligible in the growing season, a substantial groundwater recharge occurs in an off-season period and/or at the beginning of growing season. Mulching was not proved to reduce evaporation. The best type of management providing for the economical water regime appears to be a one-cut variant. Relationships between botanical composition and GR water regime are also described.

Keywords: water regime; grasslands; extensive land use; mulching

The area of grasslands has been increasing as a result of restructuring of the agriculture sector in the CR (set aside areas, grassland establishment in so called vulnerable differential zones in water protection areas – WPA); necessary management of these grasslands should support their ecological functions. One of the ecological functions of any grassland is its hydrological function substantially contributing to the formation of water resources in the landscape. It is important mainly in WPA: grasslands intercept a relatively high amount of rainfall (11–25% of annual total in cut grasslands (Mrkvička 1998), thanks to their higher content of soil organic matter, favourable soil structure and higher porosity (on average by 10% higher than in arable land, Jůva et al. 1975, cited in Rychnovská 1985). The hydrological function of an extensive low-yielding grassland is supported by its lower water consumption in comparison with intensive GR.

The objective of this paper was to estimate rainfall efficiency (water retardation in the watershed) in GR under different management systems and/or to select such a type of GR management in the conditions in question that could be applied as the most efficient in WPA with respect to water consumption by the sward. The influence of climatic conditions (rainfall) and management system on the water regime of extensive GR was evaluated.

MATERIAL AND METHODS

An experimental plot is situated in the cadaster of Klečaty commune in Tábor district; geomorphologically it lies in the Třeboň basin, at a height of 423 m a.s.l., in a moderately warm climatic area – district B 3 – moderately warm, moderately humid, with mild winter, hilly, long-term averages of precipitation and temperature (1. 1. 1901 to 31. 12. 1950): 588 mm and 7.3°C, 378 mm and 13.5°C in the growing season (precipitation in Soběslav, temperatures in Tábor), production area: potato-growing, subarea – potato- and wheat-growing, III c/3, soil: great soil group – gleyic luvic Cambisol, texture – sandy loam, geologically sandy and clay Tertiary sedimentary deposits. Table 1 shows monthly, seasonal and annual precipitation totals and average air temperatures at a nearby lysimetric station at Borkovice in 1998–2000.

At this locality, drainage lysimeters (Novodur dishes) 0.71 × 0.71 m in size (0.5 m^2) were installed at a depth of 0.6 m in 1976. Soil layers were placed into these lysimeters in the same order as natural soil. Percolating water is conducted from lysimeters to PVC bottles connected to a pipeline. Bottles are accessible in wells 1.5 m deep. Natural water regime is used. The size of one variant with four replications is 5.5 × 7.5 m = 41.25 m^2. The plot has a pipe drainage at a depth of 1.5 m.

The results of observations of grassland water regime from 1998–2000 reflect four different methods of grassland use (each variant has four replications). A one-cut or a two-cut system was used, another variant was mulching once a year (biomass was chopped with a mulching machine and left on the ground to be decomposed), and the last variant was no cut.

Table 2 shows the botanical composition of variants at the beginning and end of the trial. Except the no-cut variant, different fertilizing and intensive management of the grasslands were used by 1992 (Havelka and Šonka 1990). No fertilizers have been applied since 1993, when a two-cut variant was introduced, followed by a one-cut sys-

Table 1. Monthly, season and annual precipitation sums (mm) and average air temperatures (°C), Borkovice lysimetric station 1998–2000

Month	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.	I.–XII.	IV.–IX.
Precipitation (mm)														
1998	19.0	5.3	51.8	17.1	52.8	95.1	83.5	46.5	77.9	71.0	38.7	12.0	570.7	372.9
1999	21.0	60.2	24.4	31.9	63.7	73.1	65.1	38.5	33.9	21.4	22.9	37.1	493.2	306.2
2000	41.5	29.6	101.1	7.5	61.3	48.9	92.8	44.4	44.4	67.9	22.6	17.0	579.0	299.3
Temperature (°C)														
1998	–0.02	0.6	2.9	8.5	14.0	18.1	19.0	19.2	12.9	9.4	1.2	–1.2	8.7	15.3
1999	0.2	–0.5	5.1	8.8	14.9	17.1	20.3	18.3	16.1	8.3	2.3	–0.1	9.2	15.9
2000	–2.9	–2.1	4.1	11.0	15.3	17.9	16.5	19.0	12.7	10.7	4.7	0.2	8.9	15.4

tem since 1994 and mulching carried out since 1996. The no-cut variant, established in 1976, was applied fertilizers and a the two-cut system by 1982, since 1983 it has not been applied any fertilizers and left unused. It was established with help of contingency tables method that percentage coverage of the monocotyledons and dicotyledons plant species was in the case of the variants two cut and no cut between 1998 and 2000 significantly different.

Moisture content by weight was determined (gravimetrically) regularly at fortnightly intervals from soil layers 0.0–0.1, 0.1–0.2, 0.2–0.3 and 0.3–0.6 m on each variant at four replications; it was converted to moisture content by volume using bulk density, and the water supply of the soil profile 0.0–0.6 m was calculated. Rainfall and water runoff from the soil profile to PVC bottles were measured in the same fortnightly intervals. Actual evapotranspiration of a preceding period from the sward and soil profile 0.0–0.6 m was determined on the basis of this data ($ETA = H_S – O + W_1 – W_2$, where H_S = rainfall over the period of observation in mm, O = water runoff from a lysimeter over the period of observation in mm, W_1, W_2 = soil water supply at the beginning and end of the period of observation in mm, ETA = actual evapotranspiration in mm) – Table 3 (negative values of soil water supply represent a decrease in this supply during the growing season). The sum of these values for a period from the beginning of April to the end of September showed the value of actual evapotranspiration in the growing season (sum of ETA).

Figures 1–3 illustrate soil moisture contents in the variants of land use in 1998, 1999 and 2000 while Figures 4–6 show ETA of the variants of land use in 1998, 1999 and 2000.

Scheffe's test at a significance level 0.05 was used for statistical evaluation of significant differences in the values.

RESULTS

The results were to verify whether different botanical composition and structure of the sward of differently used GR would cause differences in the water regime of soil. In none of the growing seasons 1998–2000 was a statistically significant difference confirmed in the mean values of ETA between the variants of land use. The effect of the variant results in a decrease in ETA after the cut (except the mulching variant in 1998), but the decrease is only transitory (14–30 days). Not even a comparison of three-year totals of ETA values brought about any significant differences (Table 4). The sums of ETA for one-cut, mulching and no-cut variants gave very balanced values, the sum of ETA for two-cut variant was by 30 mm higher (i.e. a difference of 300 $m^3.ha^{-1}$ for three growing seasons). If the variants of land use were arranged according to increasing ETA, the rank of variants was different each year.

Differences in the average values of water supply in the soil profile 0.0–0.6 m (Figures 1–3) in 1998 and for the whole period 1998–2000 were significant between two-cut and mulching variants (lower ones) and the no-cut variant; no significant differences were determined in 1999 and there were significant differences between one-cut, two-cut, mulching variants and the no-cut variant in 2000 (Table 5). The moisture content increased temporarily after the cut as a result of limited evapotranspiration (except for the mulching variant in 1998) but the increase did not influence the average annual water supply in soil very much.

Water runoff from the soil profile 0.0–0.6 m was negligible in the growing season due to water use by evapotranspiration. Water runoffs to the groundwater level (GWL) are higher in the off-season period because evapotranspiration is lower. The soil profile of the mulching variant had the lowest runoff (Table 4). The surface and subsurface runoff were negligible.

If differences between the growing seasons 1998–2000 were evaluated for each variant, other results were obtained. All experimental variants had the lowest ETA in 1999 and highest ETA in 1998. There were statistically significant differences between the values for these years, and except for the mulching variant, significant differences between 1999 and 2000 were also demonstrated (Table 6). Different rainfall and net radiation balance can explain these differences in the years of observation.

Average values of water supply in the soil profile 0.0–0.60 m were the highest in all variants in 1998 (highest rainfall) and lowest in 2000 (little rainfall in April–May, the soil was desiccated and subsequent rainfall compensated for

Table 2. Botanical composition of the sward and coverage of plant species at the beginning and end of the trial (percentage of reduced projective dominance)

Variant of land use	One cut		Two cut				Mulching		No cut	
Year	1998	2000	1998		2000		1998	2000	1998	2000
Cut No.			I.	II.	I.	II.				
Botanical species										
Agrostis capillaris	10	1	8	3	5	4	49	22	15	12
Anthoxanthum odoratum			+		2					
Arrhenatherum elatius	13	44			+	+		3	22	23
Carex hirta									8	4
Dactylis glomerata	9	+	+	3	1	1	23	39	7	10
Deschampsia caespitosa									3	
Elytrigia repens								+		
Festuca pratensis		8			+	2	1	16		2
Festuca rubra	9	5	46	48	3	7		+		+
Luzula campestris					+					
Phalaroides arundinacea									3	+
Phleum pratense		+			+			+		
Poa pratensis		+			+			+		+
Trisetum flavescens				+						
Grasses in total	**41**	**59**	**54**	**54**	**12**	**14**	**73**	**80**	**53**	**51**
Lotus corniculatus		1								
Trifolium dubium	+	4	3		58			+		
Trifolium pratense		+	+	+	9	22				
Trifolium repens		+	2		7	1		+		
Vicia angustifolia			1							
Clover crops in total	**+**	**5**	**6**	**+**	**74**	**23**		**+**		
Achillea millefolium		3		3	+	5				+
Alchemilla vulgaris										+
Bellis perennis		+	+		+	+				
Campanula patula		+			+	+		+		+
Cerastium arvense		+						+		+
Convolvulus arvensis						+		+		+
Equisetum arvense						+		1		
Galium mollugo	3	3		5	2	9			34	19
Hieracium sp.						+				
Hypericum perforatum					+	+				+
Leontodon autumnalis		+	2	+	+	1				
Plantago lanceolata	19	8	23	29	9	37		+	+	+
Prunella vulgaris		+				+				
Ranunculus repens	1	+				+	+	+		
Rumex acetosa			+		+	+	+	+	+	+
Rumex crispus										+
Stellaria graminea					+	+	+	+		
Taraxacum officinale		1			+			+		
Urtica dioica									8	3
Veronica chamaedrys		1			+		+	1		
Other species in total	**23**	**17**	**25**	**37**	**12**	**53**	**1**	**3**	**42**	**24**
Voids	**36**	**19**	**15**	**9**	**2**	**10**	**26**	**17**	**5**	**25**

the moisture need of the sward) except the no-cut variant which was driest in 1999. There were statistically significant differences between 1998 and 2000 (in all variants), between 1999 and 2000 in the mulching variant and between 1998 and 1999 in no-cut variant (Table 6). Although the rainfall was lowest in 1999, the average water supply in soil was not lowest that year because rainfalls from the beginning of vegetation to mid-July accounted for 88.4% of the rainfall total over the growing season and the rainfall deficit (mid-July to mid-September) occurred in that part of the growing season when the moisture need of plants is not so high as in the first half of vegetation.

Water runoff from the soil profile 0.0–0.60 m in the growing season was negligible in any year. Evaporation in form of ETA is an important process preventing water runoff from this soil profile, i.e. the supply of water to the

Table 3. Water regime balance of the soil profile 0.0–0.6 m in the experimental variants in growing seasons 1998–2000 (mm)

Year	1998				1999				2000			
Variant	rainfall	runoff	soil water supply	ETA	rainfall	runoff	soil water supply	ETA	rainfall	runoff	soil water supply	ETA
One cut	347.7	0.08	–15.33	362.95	237.9	1.44	–92.46	328.92	300.1	6.63	–57.40	349.36
Two cuts	347.7	0.09	–24.20	371.81	237.9	2.45	–99.77	335.22	300.1	6.09	–77.02	368.40
Mulching	347.7	0.10	–12.94	360.54	237.9	0.06	–97.76	335.60	300.1	0.08	–51.65	351.51
No cut	347.7	3.68	–30.32	374.34	237.9	2.91	–85.67	320.66	300.1	9.04	–67.22	351.69

groundwater level. Water runoff from the soil profile in an off-season period depends on the amount of rainfall and on the distribution of rainfall in time.

It was established that the sum of ETA in the growing season (Table 4) increases with increasing amount of rainfalls (the sward has enough water for evaporation and transpiration at its disposal, water output need not be limited). However, evaluation of this assumption in fortnightly intervals did not confirm such a relation of proportionality in all cases. It is also influenced by the pattern of meteorological conditions (ETA decreases in a longer period of rains accompanied by low air temperatures and low saturation deficit) and by growth stage of the sward (aboveground biomass).

Besides the above results, the following relationships between the botanical composition of swards and their water regimes are presented. *Dactylis glomerata*, *Agrostis capillaris* and *Festuca pratensis* are dominant spe-

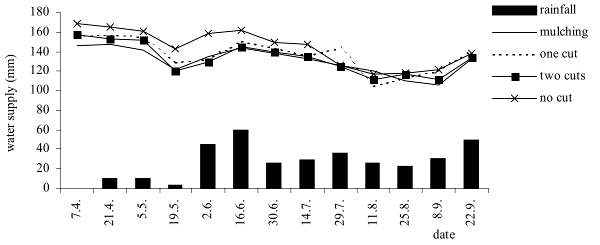

Figure 1. Klečaty 1998, water supply (mm) in soil (0–60 cm) in different variants of land use

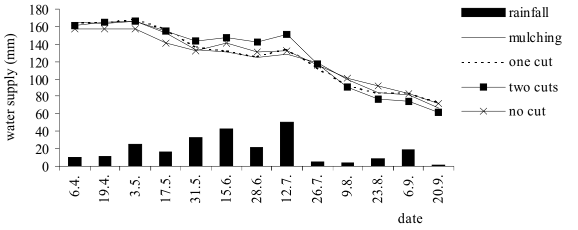

Figure 2. Klečaty 1999, water supply (mm) in soil (0–60 cm) in different variants of land use

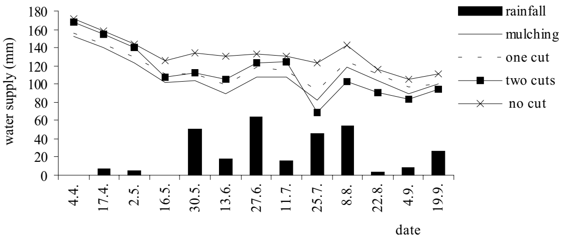

Figure 3. Klečaty 2000, water supply (mm) in soil (0–60 cm) in different variants of land use

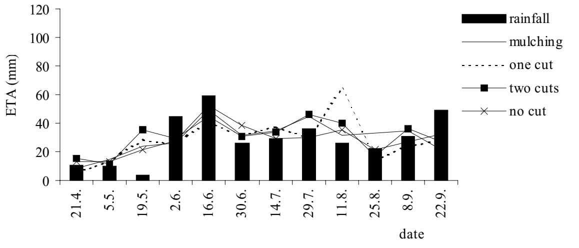

Figure 4. Klečaty 1998, ETA values in mm in differently used swards

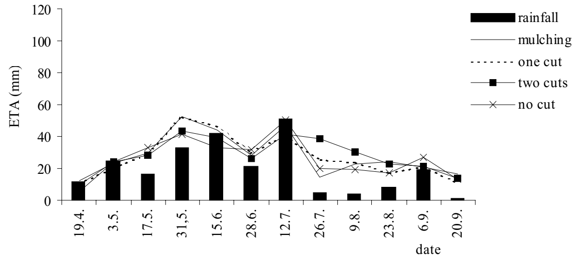

Figure 5. Klečaty 1999, ETA values in mm in differently used swards

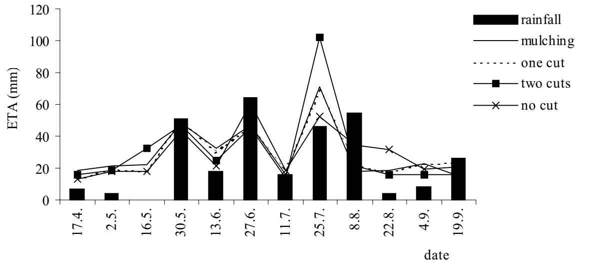

Figure 6. Klečaty 2000, ETA values in mm in differently used swards

cies in the mulching variant. *Festuca pratensis* and *Dactylis glomerata* were planted in 1985; *Agrostis capillaris* appeared after the sward fertilizing was terminated (Table 2). *Dactylis glomerata* is maintained by generative propagation (late cut, mid-July), the yield is very low because no fertilizing was applied – Table 7 (not even did the nutrients released from decomposed mulch biomass increase the yield of mulching variant).

Arrhenatherum elatius, *Festuca rubra*, *Festuca pratensis*, which were planted in 1985, and *Plantago lanceolata* and *Gallium mollugo* are dominant species in the one-cut variant. The number of dicotyledonous plants considerably increased in the three years of observation, *Dactylis glomerata* and *Agrostis capillaris* almost disappeared while *Trifolium dubium* appeared in 2000. *Arrhenatherum elatius* spread to the sward from the environs (it was not a part of planted mixed swards) and is maintained by generative propagation as a result of late (July) cut.

Festuca rubra, *Dactylis glomerata*, *Festuca pratensis*, *Trifolium pratense*, *Trifolium repens* are originally planted species in the two-cut variant, *Agrostis capillaris*, *Trifolium dubium*, *Plantago lanceolata, Achillea millefolium* and *Gallium mollugo* have spread spontaneously. *Dactylis glomerata* is receding due to a lack of nutrients, grasses with low requirement for nutrients persist, but clover crops and other dicotyledonous plants (sufficient light, absence of nitrogen fertilizing) are spreading to occupy their place. Moisture requirements of this group of plants (dicotyledons) apparently caused the highest sum of evapotranspiration in this variant over the three growing seasons as well as the highest water consumption from water supply (Table 4).

The botanical composition of no-cut variant consists of *Arrhenatherum elatius*, *Dactylis glomerata*, which are the species originally planted in 1976; *Agrostis capillaris*, *Carex hirta*, *Phalaroides arundinacea*, *Deschampsia caespitosa*, *Alopecurus pratensis*, *Urtica dioica* and *Galium molllugo* are also present. This variant has the highest moisture content on average of all years (as documented by botanical composition), and water runoff from its profile is also highest. As ETA has similar values like in the other variants, the highest moisture content in this variant is caused by lower evapotranspiration in the period not included in observations (2nd half of September to early April), when the effect of dead plant residues causes lower intake of global radiation due to higher albedo, and lower evaporation. The spread of *Alopecurus pratensis* was large (15% on average) in 1999; it has an intensive water regime and can be considered as a cause of lower moisture content in this variant in 1999 than in 1998 (Table 4).

DISCUSSION

To provide for water transfer from the soil profile to groundwater level and the lowest consumption of water by evapotranspiration, the most suitable variant among acceptable variants of GR use (mulching, one cut, two

Table 4. Summary values of evapotranspiration, precipitation, average values of water supply and water runoff from the soil profile 0.0–0.6 m (mm) in the variants of land use and growing seasons

Year	1998	1999	2000	1998 –2000	1998	1999	2000	1998 –2000	1998	1999	2000	1998 –2000	1997 /1998	1998 /1999	1999 /2000	1998 –2000
Variant	actual evapotranspiration				soil water supply				season runoff				off-season runoff			
One cut	362.95	328.92	349.36	1041.23	137.22	125.72	116.21	126.38	0.08	1.44	6.63	8.15	8.18	32.86	10.47	51.52
Two cuts	371.81	335.22	368.40	1075.42	132.84	127.07	113.51	124.47	0.09	2.45	6.09	8.73	6.10	22.11	10.83	39.04
Mulching	360.54	335.60	351.51	1047.64	130.92	124.18	109.36	121.49	0.10	0.06	0.08	0.24	3.32	15.47	10.30	29.10
No cut	374.34	320.66	351.69	1046.68	144.49	124.18	132.67	133.78	3.68	2.91	9.04	15.63	7.74	25.14	13.17	46.05
Precipitation	347.7	237.9	300.1	885.7	347.7	237.9	300.1	885.7	347.7	237.9	300.1	885.7	180.9*	235.5*	283.3*	699.7*

* the values of off-season precipitation sums were taken from Borkovice lysimetric station

Table 5. Statistically significant differences between the variants of land use (for the particular years and the whole period of observation), Scheffe's test, significance level 0.05

Year	1998	1999	2000	1998 –2000	1998	1999	2000	1998 –2000	1998	1999	2000	1998 –2000	1997 /1998	1998 /1999	1999 /2000	1998 –2000
Variant	actual evapotranspiration				soil water supply				season runoff				off-season runoff			
One cut	×	×	×	×	××	×	×	××	×	×	×	×	×	×	×	×
Two cuts	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Mulching	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
No cut	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×

cuts) is a one-cut system, as documented by the results. No-use of GR cannot be recommended due to negative impacts on the environment (botanical composition, nutrient availability, microbiological activity, etc.).

The fact that the saving effect of mulching on water consumption by the sward was not proved cannot be explicitly confirmed in general. Such conclusion is applicable only in relation to the given botanical composition of GR and the date (July) and number of cuts (one) of mulching variant.

We did not find enough literary sources that would solve similar problems. Kvítek et al. (1998) evaluated differences in the water regime of mulching, two-cut and one-cut variants on the same experimental plot in 1995–1997. There were not any statistically significant differences in ETA of the studied variants; ETA depended on rainfall amounts in the years of observation. The assumption of a significant increase in the soil moisture content of mulching variant was not confirmed. Water runoff from the soil profile was minimal. The results are consistent with findings of this paper.

Fiala and Gaisler (2000) measured water runoff from the soil profile at a depth 0.2 and 0.4 m in a grassland under different management systems that was left unused for 10 years before their trial started. The highest values of water runoff from the soil profile 0.0–0.4 m were demonstrated at a site with one cut per year without biomass removal (7.4% of annual precipitation, i.e. 67.25 mm) and at a site with mulching three times a year (6.8% of precipitation, i.e. 61.80 mm). There was no water runoff from lysimeters at sites with two cuts per year and biomass removal and with mulching in September. The highest water amount at a depth 0.2 m was intercepted in a two-cut variant with biomass removal (6.6% of precipitation, i.e. 60 mm) and at a site with mulching in September (7.5% of precipitation, i.e. 68.16 mm). Water runoff from the soil profile 0.0–0.2 m at an unused site amounted to 8% annual precipitation (72.7 mm).

Interesting results were published in the paper by Cernusca et al. (1998), who investigated ecological processes in differently used GR (cuts and no land use of meadows and pastures) in the mountainous landscape of Europe (the Alps, Pyrenees, Scottish Highlands). They drew the following conclusions from presented as well as previous findings: GR where the intensity of use decreases to the absence of any cuts have lower ETA, and therefore the higher turbulent flow of heat to the atmosphere. Lower ETA is a result of high accumulation of dead plant residues in the sward that cannot utilize the solar radiation for evaporation, and of lower availability of nutrients to plants (reduced microbiological activity of soil). The evapotranspiration values from 28. 5. to 4. 10. 1997 were 395 mm in intensively used meadow, 364 mm in pasture and 362 mm in meadow left unused. Tappeiner and Cernusca (1998) demonstrate (on the same localities) that the net radiation efficiency for the process of evapotranspiration is influenced by the sward structure. 72% of net radiation is used for ETA by cut meadow, 59% by pasture (more

Table 6. Statistically significant differences between the years of land use (for the variants of land use), Scheffe's test, significance level 0.05

Variant	1×	2×	M	N	1×	2×	M	N	1×	2×	M	N	1×	2×	M	N
Year	actual evapotranspiration				soil water supply				season runoff				off-season runoff			
1998	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
1999	×	×	×	×	××	××	×	×	××	×	×	×	×	×	×	×
2000	×	×	××	×	×	×	×	×	×	×	×	×	×	×	××	××

1× – one-cut variant, 2× – two-cut variant, M – mulching, N – no-cut variant
Water runoff in the off-season period was measured in these periods: 26. 9. 1997–7. 4. 1998, 23. 9. 1998–6. 4. 1999, 21. 9. 1999–4. 4. 2000
Late thawing influenced seasonal water runoff in 2000, which means water accumulated over the winter ran off in April, i.e. at the beginning of vegetation

Table 7. Dry mass yields (t.ha^{-1}) and dates of cuts in the years of observation and variants of land use

Variant	One cut		Two cuts			Mulching	
Year	yield	dates of cut	yield	dates of cut		yield	dates of cut
1998	1.28	14. 7.	1.35	9. 6.	8. 9.	1.33	14. 7.
1999	2.47	14. 7.	1.81	2. 6.	9. 9.	2.89	14. 7.
2000	1.22	13. 7.	2.87	1. 6.	6. 9.	1.70	13. 7.

energy is absorbed by the soil because the sward is low) and 58% by uncut meadow (presence of dead plant residues). In agreement with the above results higher evapotranspiration values were recorded on our experimental plot in the variant with more intensive land use (two cuts) than in the variant with low intensity of land use or in no-cut variant.

The findings can be summarized in form of the relationship between land use intensity and the sum of ETA: the sward with two cuts has higher water consumption than the sward with one cut (including mulching) or uncut sward.

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ABSTRAKT

Vliv srážek a extenzivního využití travních porostů na vodní režim

V letech 1998 až 2000 byl pomocí drenážních lyzimetrů zjišťován a porovnáván vodní režim extenzivně využívaných travních porostů (varianty jednou, dvakrát ročně sečené, nesečené, mulčované). Pokusné varianty měly odlišné botanické složení i výnos, přesto nebyl v jednotlivých letech zaznamenán statisticky průkazný rozdíl v jejich vodním režimu (pouze půdní vlhkost nesečené varianty byla průkazně vyšší než u ostatních variant). Určující vliv na vodní režim travních porostů má úhrn srážek vegetační sezony, způsob využití ovlivňuje vodní režim travních porostů pouze bezprostředně po seči. Bylo zjištěno, že odtok vody z půdního profilu 0,0 až 0,60 m (dotace hladiny podzemní vody) ve vegetačním období je zanedbatelný, k významnějšímu doplňování hladiny podzemní vody dochází pouze v mimovegetačním období, resp. na počátku vegetačního období. Vliv mulčování na omezení výparu nebyl prokázán. Z hlediska úspornosti vodního režimu se jako nejvhodnější typ managementu ukazuje jednosečné využití. Dále jsou uváděny souvislosti mezi botanickým složením a vodním režimem travních porostů.

Klíčová slova: vodní režim; travní porosty; extenzivní využití; mulčování

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