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THE EFFECT OF MINERAL FERTILIZATION ON BELOWGROUND PLANT BIOMASS OF GRASSLAND ECOSYSTEMS

Ján Tomaškin, Ján Jančovič, Ľuboš Vozár, Judita Tomaškinová

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Abstract

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Aim of the work was to determine the effect of different doses of mineral fertilization on belowground and aboveground plant biomass production of three different types of grasslands, to state R:S ratio (root:shoot) and turnover period of belowground plant biomass of grasslands. In the contribution, we assess production of underground biomass, tillering zone and aboveground biomass on three types of grasslands – permanent grassland (PG), over-sown grassland (OSG) and temporary grassland (TG) in sub-mountain area of central Slovakia. There were applied four levels of mineral nutrition in each grassland (non-fertilized variant, var. 30 kg.ha^{-1}P and 60 kg.ha^{-1} K. var. 90 kg.ha^{-1} N + $P_{30}K_{60}$, var. 180 kg.ha^{-1} N + $P_{30}K_{60}$). The root biomass has the most significant share in the total biomass of grasslands (49.9–54.2 %), followed by tillering zone (33.3–36.0%) and with the lowest share of aboveground biomass (11.9–16.8 %). A dominant share of root biomass and tillering zone ensure significant extra-productive functions of grasslands that contribute to the stability of agriculture landscape. We recorded the lowest amounts of root mass on TG (7.31 t.ha^{-1}) and OSG (7.76 t.ha^{-1}), the highest amounts on PG (8.52 t.ha^{-1}). The specific nitrogen stimulating influence on root biomass production has been proven. Production of tillering zone was lower on OSG and TG (5.11 or 5.42 t.ha^{-1}), significantly higher on PG (5.72 t.ha^{-1}). We observed a significantly higher production of tillering zone with variants which were fertilized with nitrogen than on non-fertilized and PK fertilized. The lowest harvests of aboveground biomass were noticed on TG (5.80 t.ha^{-1}), significantly higher on PG and OSG (6.35 or 6.54 t.ha^{-1}). Mineral nutrition had a significant impact on production of aboveground biomass.
R:S ratio of the assessed grasslands achieved the values from 4.02 to 5.16. Higher values on PG (5.16) are indicating its higher resistance to drought. Turnover time of root biomass was the longest on PG 3.5–5.0 years, on OSG and TG 2.5–3.5 years. Based on achieved results, we recommend using the fodder plants cultivation system on PG or OSG. Permanent grasslands are proved as ecologically more stable and more resistant to drought than temporary grasslands; they can together with optimal mineral nutrition provide adequate production of root biomass (8.5 t.ha^{-1}) and a harvest of aboveground biomass (6.3 t.ha^{-1}).

aboveground biomass, grass sod, grassland, plant biomass, root, R:S ratio, tillering zone, turnover time of root biomass

Grass ecosystems are providing besides a productive function also significant extra-productive functions (erosion control, retention, biofiltration, environmental). Grass sod (root biomass and tillering zone) provides these functions and makes a dominant 80–85% share in total production of grassland biomass. KRAJČOVIČ, ONDRÁŠEK (2007) consider grass sod as a central component of semi-natural grassland, which is physical, morphological, physiological and metabolic interface between aboveground and underground part of the biocenosis with important specific characteristics and functions for aboveground and underground biomass.

Grasslands ensure a significant function of ecological stabilization in agriculture landscape. They dispose of homeostasis and adaptive mechanisms that successfully react to several negative anthropogenic effects and factors of environment; they are also resistant to longer drought period or water logging. Grasslands significantly contribute to the soil protection from erosion by their massive root system. Dense over-rooting system of sod layer enriching the soil of organic matter and humus in the mineralization process. Their adequate supply in the soil increases the retention capacity of agricultural landscape (RYCHNOVSKÁ *et al*., 1985; FIALA, 2007).

The grasslands have contributed to the ecological stability by relatively closed mass and energy flow circulation. Practically, the whole biomass of roots and tillering zone enter to the closed natural biomass circulation. The opinions on the production of root biomass of grass swards with effect of fertilization are various. ÚLEHLOVÁ, HALVA, VRÁNA (1981), SNYDER, CISAR (2000), VELICH (1986) and others quote an increase in the root biomass amount after the application of mineral nutrients. On the contrary, FIALA (1985, 2007) and MRKVIČKA, VESELÁ, SKÁLA (2004) quote the root biomass reduction on grass swards after the use of higher doses of nitrogen fertilization.

We can assess the meadow-pasture grassland as highly stable and resistant ecosystem to adverse negative environmental effects in comparison with the agro-ecosystem on arable land where a major part of the biomass is used beyond its border (KUTSCHERA, 1991).

Aim of the work was to determine the effect of different doses of mineral fertilization on belowground and aboveground plant biomass production of three different types of grasslands, to state R:S ratio (root:shoot - root biomass weight rate on aboveground swards mass) and turnover period of belowground plant biomass of grasslands. Achieved results are documented ecological and environmental importance of root biomass of grasslands.

MATERIALS AND METHODS

In this article, we report the results which are a summary of scientific knowledge included the solutions of research projects solved at Department of Research Institute of Grass Swards and Mountain Agriculture in Banská Bystrica – Slovak Republic.

Problems of accumulation and root system creation of grass ecosystems in various conditions of fertilization we monitored during the years 1993–1998 at three vegetation types: permanent grassland (PG), over-sown grassland (OSG) and temporary grassland (TG). The experiment took place at Radvaň – by the Suchý vrch (48° 44´N, 19° 09´E) at an altitude of 460 m above the sea, in Banská Bystrica, Central Slovakia. In the experiment was used block design in four replications. The area belongs to the region Kremnické and Starohorské vrchy. Climatological characteristic: a slightly cool and a slightly wet area. Exposition to the northern slopes of 5 °C. Average annual precipitations are 746 mm, 422 mm per growing season. The average annual temperature is 8.21 °C and 15.03 °C for vegetation during a growing season. The basic meteorological data, mean air temperature (°C) and rainfall sum (mm) during the growing season and the year for reporting period are shown in Tab. I.

I: *Mean air temperature (°C) and rainfall sum (mm) during growing season and year*

Month	Year											
	1993	1994	1995	1996	1997	1998	1993	1994	1995	1996	1997	1998
	Mean air temperature (°C)						Rainfall sum (mm)					
I	−1.3	0.9	−2.4	−3.1	−3.1	0.8	37.0	86.0	68.0	67.3	25.5	31.8
II	−1.6	−0.2	2.5	−3.4	0.4	3.5	31.8	5.5	71.8	64.7	48.2	2.6
III	2.8	5.4	3.0	0.3	3.3	2.2	7.1	61.2	109.1	41.5	20.4	33.4
IV	9.1	9.1	8.7	9.1	5.7	9.5	13.4	121.1	78.6	132.5	39.0	99.2
V	16.2	13.3	13.1	14.7	13.1	13.1	58.5	144.5	126.1	143.2	47.9	47.8
VI	16.5	17.4	16.6	17.0	16.1	18.1	106.7	20.8	101.3	101.4	113.2	65.5
VII	16.2	21.5	21.2	16.2	17.4	18.7	47.3	41.3	44.2	53.0	144.8	59.7
VIII	17.7	18.8	17.4	17.6	18.9	18.6	65.8	124.7	99.4	138.5	44.0	33.8
IX	12.9	15.6	11.8	10.1	13.9	13.7	44.8	112.3	118.7	62.3	13.9	188.8
X	9.8	6.7	9.8	9.1	6.0	9.2	133.4	101.7	5.3	50.4	38.2	179.8
XI	1.1	4.3	0.6	5.8	3.6	0.8	62.7	55.3	40.4	86.8	181.9	53.0
XII	0.9	0.3	−1.1	−3.8	1.0	−3.8	186.2	42.9	72.8	29.7	48.8	34.3
IV–IX	14.8	16.0	14.8	14.1	14.2	15.3	336.5	564.7	568.3	630.9	402.8	494.8
I–XII	8.4	9.4	8.4	7.5	8.0	8.7	794.7	917.3	935.7	971.3	765.8	829.7

(Source: Department of Meteorological Service Banská Bystrica)

The Lang's rain factor is equal to 106. The snow cover lasts for 80 days. The geological substrate of habitat consist weathering of andesite, a soil type is cambisol. Acid soil with pH/KCl = 4.34, C_{ox} = 35.1 g.kg^{-1} and N_t = 2.74 g.kg^{-1}.

The permanent grass swards belong to *Trisetetum flavescentis* coenosis. (*Arrhenatherion* Union). The grass determinate the coenosis physiognomy, especially the dominant species *Trisetum flavescens* and other valuable grass as *Poa pratensis, Dactylis glomerata* and *Arrhenatherum elatius*. Fabaceous plant types like *Trifolium repens, Trifolium pratense* and *Lotus corniculatus* improve the value of swards. The most significant species of herbs is *Taraxacum officinale*, which ranks among the subdominant of coenosis. The over-sown grass swards represent the original permanent grass swards improved by seeding the trifoil-grasses mixes consisting of *Dactylis glomerata* cv. Rela (2 kg seeding amount), *Festulolium* cv. Felina (6 kg seeding amount), *Lolium perenne* cv. Metropol (4 kg seeding amount), *Trifolium pratense* cv. Sigord (1.5 kg seeding amount), *Trifolium repens* cv. Huia (1 kg seeding amount per ha^{-1}). The temporary grass swards consists the same composition mixes as the over-sown grass swards with the double seeding amount of the individual species. Temporary and over-sown grassland were created during the spring in 1991.

Each type of swards included four fertilizing types:

Variant 1 – control – non-fertilized variant,
Variant 2 – 30 kg.ha^{-1} P and 60 kg.ha^{-1} K (fertilized once in spring),
Variant 3 – 90 kg.ha^{-1} N, 30 kg.ha^{-1} P and 60 kg.ha^{-1} K (dividing N 3x30 kg to cuts; fertilized with P and K once in spring),
Variant 4 – 180 kg.ha^{-1} N, 30 kg.ha^{-1} P and 60 kg.ha^{-1} K (dividing N 3x60 kg to cuts; fertilized with P and K once in spring).

The grass swards have been used in three cuts. Sampling of roots and tillering zone of grass swards was realized by method of monoliths sampling with the steel rollers. Sampling was carried out three times per year from each type and variant of grassland at the beginning of vegetation season, just after cut of swards and at the end of the vegetation season. In the article we present average results of five samples. The sampling was realized by using the steel roller (50 mm diameter) to a soil depth of 100–120 mm and was repeated for 20 times. We cut 20 mm top part from the monolith that forms the tilling zone. Sampled roots and tillering zone were washed out by a stream of warm water in sieves. The samples were dried at 60 °C and determined the weight of dry mass.

Production of aboveground biomass was monitoring with belowground biomass and tillering zone sampling. Results of aboveground stand production were acquired from yields during the each cuts of vegetation season. The weight of green mass was determinate by weighting and subsequently converted to the absolute dry mass. The data were applied to assess the R:S ratio (root biomass weight rate on aboveground swards mass). In accordance with the methodology, which provides RYCHNOVSKÁ *et al.* (1987), we also determined the turnover rate of root biomass (TO in %) according to the following ratio:

$$TO = (R_{max} - R_{min})/R_{max} \times 100,$$

when R_{max} and R_{min} are maximum and minimum amount accumulated root biomass during the growing season. We also determined the turnover period of root biomass (in years) according to the ratio: 100/TO.

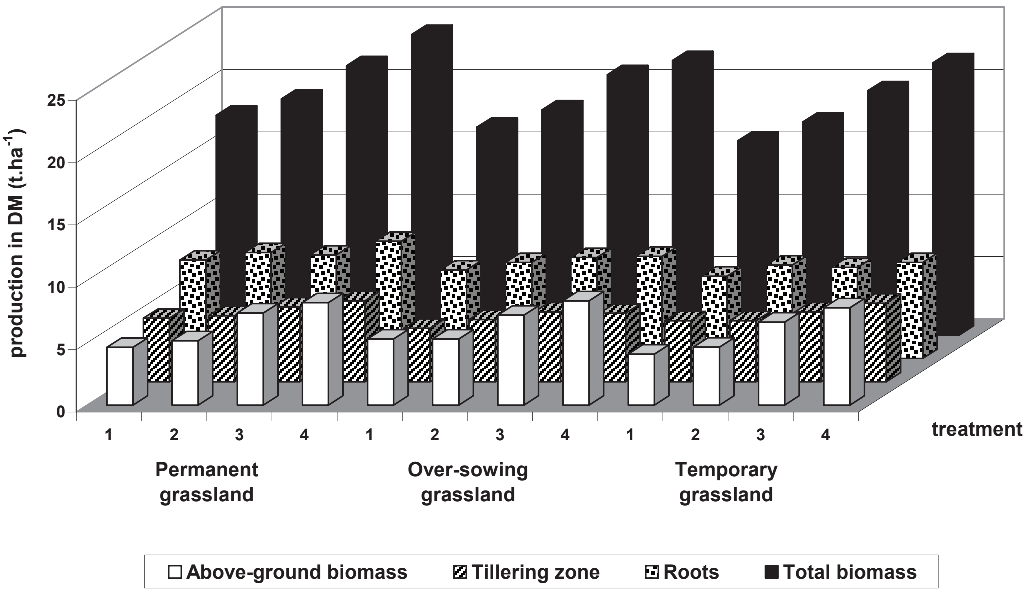
The results of the root biomass production and R:S ratio were evaluated statistically by multiple (multifactor) analysis of the variance at 95% level of LSD test (Statgraphics software version 5.0), with the following variability: three types of grass swards (PG, OSG, TG), four mineral nutrition variants (non-fertilized variant, $P_{30}K_{60}$, N 90 + $P_{30}K_{60}$, N 180 + $P_{30}K_{60}$) and six years of monitoring (1993–1998).

RESULTS AND DISCUSSION

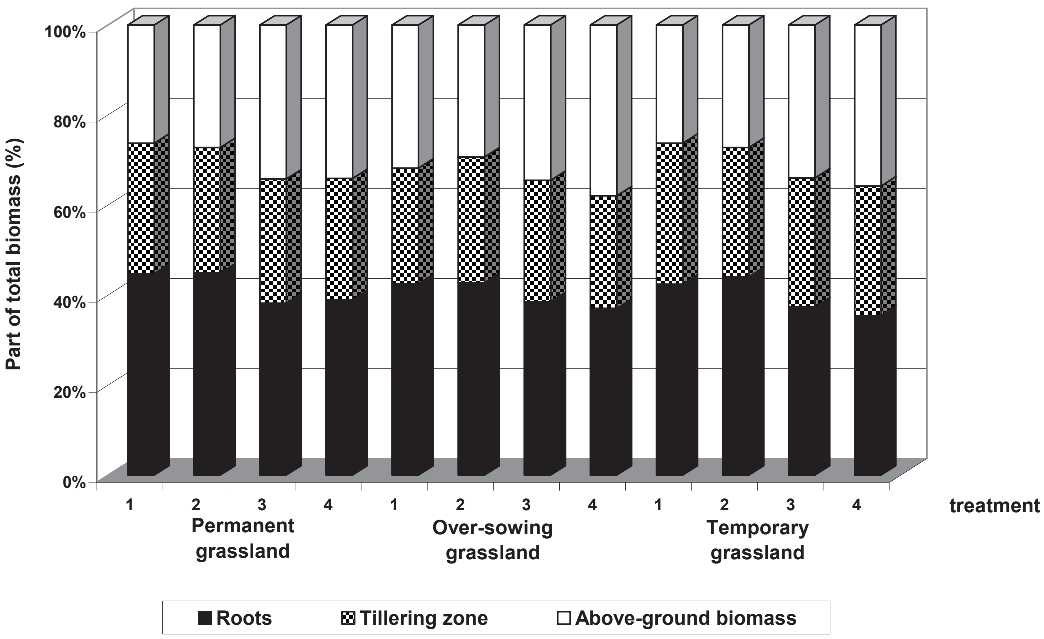
An overview of the production of roots, tillering zone (average of three sampling during the growing season of the years 1993–1998), aboveground phytomass (the amount of harvests from three cuts during the growing season of the years 1993–1998) and total phytomass of grassland are presented in Tab. II.

II: *Primary production of grassland (in DM t.ha^{-1})*

Sward	Permanent grassland				Over-sown grassland				Temporary grassland			
Treatment	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
					Production (t.ha^{-1})							
Roots	7.90	8.51	8.26	9.39	7.10	7.73	8.06	8.16	6.61	7.54	7.33	7.75
% of total biomass	44.78	44.91	38.22	38.95	42.54	42.80	38.56	37.05	42.46	44.09	37.36	35.47
Tillering zone	5.11	5.28	5.97	6.50	4.28	5.04	5.63	5.51	4.87	4.91	5.62	6.29
% of total biomass	28.99	27.89	27.61	26.95	25.68	27.89	26.94	25.00	31.29	28.72	28.66	28.78
Above-ground biomass	4.63	5.16	7.39	8.22	5.30	5.30	7.21	8.36	4.09	4.65	6.66	7.81
% of total biomass	26.24	27.21	34.18	34.09	31.78	29.31	34.50	37.94	26.25	27.20	33.97	35.75
Total biomass	17.64	18.95	21.61	24.12	16.68	18.07	20.89	22.02	15.58	17.10	19.61	21.85



1: *Primary production of grassland (average 1993–1998)*



2: *Structure of total biomass of grassland (average 1993–1998)*

Primary production of assessed grassland is graphically displayed in Fig. 1.

Root biomass has the most significant share in the total phytomass, followed by production of aboveground plant biomass; the lowest production was recorded in the area of tillering zone. Percentages of root biomass, tillering zone biomass and aboveground plant biomass in the total primary production of grassland are displayed in Fig. 2.

The amount of root biomass represents the highest percentage share of total biomass (35.5–44.9 %), tirelling zone 25.0–31.3 % and aboveground biomass 26.2–37.9 % (Tab. II). With a recalculation of total phytomass on average cut, a share of root biomass is markedly higher (49.9–54.2 %), followed by tillering zone (33.3–36 %) and the lowest percentage makes above-ground plant biomass (11.9–16.8 %). ROB (1983) assumes that perennial ecosystems are capable of producing belowground and aboveground biomass in a wider ratio than annual ecosystems. Production of belowground biomass could exceed production of aboveground biomass in perennial ecosystems. Our results confirm this assumption.

KRAJČOVIČ *et al.* (1988) publishes data about the percentage stand of individual components of

III: *Evaluation of grassland primary production*

Variability factor		Production (in DM $t.ha^{-1}$)				
		Roots	Tillering zone	Above-ground biomass	Total biomass	R:S
Sward	**PG**	8.515 b	5.716 b	6.348 b	20.579 b	5.16 b
	OSG	7.762 a	5.114 a	6.540 b	19.416 ab	4.02 a
	TG	7.307 a	5.423 ab	5.803 a	18.533 a	4.27 a
LSD $\alpha_{0.05}$		**0.71523**	**0.52430**	**0.45829**	**1.23704**	**0.79522**
Treatment	**1**	7.203 a	4.757 a	4.673 a	16.632 a	5.46 b
	2	7.927 ab	5.077 a	5.033 a	18.037 a	5.47 b
	3	7.882 ab	5.739 b	7.086 b	20.706 b	3.68 a
	4	8.434 b	6.098 b	8.129 c	22.662 c	3.33 a
LSD $\alpha_{0.05}$		**0.82587**	**0.60542**	**0.52918**	**1.42841**	**0.91824**
Year	**1993**	10.915 d	8.247 d	4.431 a	23.593 d	8.78 c
	1994	9.002 c	6.211 c	7.721 c	22.933 d	3.59 a
	1995	6.317 a	3.440 a	5.747 b	15.503 a	3.40 a
	1996	6.082 a	3.540 a	7.305 c	16.927 ab	2.62 a
	1997	7.048 ab	5.076 b	7.431 c	19.555 c	3.09 a
	1998	7.804 b	5.993 c	4.748 a	18.545 bc	5.42 b
LSD $\alpha_{0.05}$		**1.01148**	**0.74148**	**0.64811**	**1.74943**	**1.12461**

a, b, c, d – significant differences

total plant biomass. He analyses the structure of the total plant biomass in grass ecosystem at an average cut with three-cuts use. Roots represented share of 28–41%, tillering zone 54–65% and production of aboveground plant biomass a share of 5–8%.

We evaluated production of roots, tirelling zone, aboveground plant biomass and total plant biomass of grassland by multiple analysis of variance (LSD test α 0.05), where as the factors of variability were represented: 3 different types of vegetation (PG, OSG, TG), 4 variants of mineral nutrition (non-fertilized variant, $P_{30}K_{60}$, N 90 + $P_{30}K_{60}$, N 180 + $P_{30}K_{60}$) and 6 years of research (1993–1998). Evaluation is presented in Tab. III.

Grassland produced 7.20–8.43 $t.ha^{-1}$ of dry root mass in depending on the grass swards cultivation type and mineral nutrition. FIALA, JAKRLOVÁ (1987) recorded the higher production. They state that the annual production of belowground biomass of different types of meadow swards in Českomoravská vrchovina is about 11 $t.ha^{-1}$ (higher values were reached in fertilized swards) and is 2–3 times higher than aboveground primary production.

We recorded that there has been the lowest amount of root biomass on the temporary grasslands – 7.31 $t.ha^{-1}$ of DM, higher amounts on the over-sown grasslands – 7.76 $t.ha^{-1}$ and significantly the highest amount on the permanent grasslands – 8.52 $t.ha^{-1}$ of dry mass of root biomass (Tab. III). TESAŘOVÁ (1990) had also published the root biomass shortage on the renewed swards (TG) in comparison with natural swards (PG). She proves it by some soil physical properties improvement after grass swards renewal (reduction of moisture, temperature incensement, soil aeration improvement), which speeds up decomposition of herb waste and soil organic mass. On the other hand, herb waste enters to soil decreases on the renewed grass swards in comparison with the semi-natural ones. The unbalance between input and output of the organic substances can be one of the main reasons substantial decrease of humus in soils restored meadow swards and can even cause the smallest amount of root mass in our experiment.

Reducing the amount of root biomass on TG against PG also state HRABĚ, PAVLÍČEK (1994), who reported 22.38 $t.ha^{-1}$ on PG, while 20.89 t. ha^{-1} of root biomass on TG, what represents a decrease of 6.7%. GÁBORČÍK, KOHOUTEK (1999) also report root biomass decrease on the temporary grass swards in comparison with that on the permanent one. Authors studied a root system of grassland in mountain area (Liptovská Teplička, 960 m a.s.l.), on the parallel ecological experiment such as this contribution deals with. They state that an annual application of mineral fertilizers causes an increase of roots in permanent and in temporary grassland. A weight of the root system increases in PG, while a maximum increase of roots shows application of PK fertilizer in TG. Temporary grassland is mostly made up of cultivated species of grasses and legumes, which have a different strategy of assimilate distribution between belowground and underground part of vegetation. This is reflected in their stability and reaction of the root system for the application of mineral fertilizers. Ploughing of autochthonous grassland and temporary vegetation establishment based on fodder plant species had a negative impact on root weight, which decreased in average of 56.5 %.

Evaluation of mineral nutrition impact on production of root mass is presented in the following part of the contribution. The application of mineral nutrition constitutes the additional factor affecting the root biomass amount along with grass swards cultivation in agriculture. The mineral nutrients often feature different effect. We reported the lowest root biomass amounts on the non-fertilized swards (7.20 t.ha^{-1} of dry mass), the balanced amounts on the swards fertilized with doses of 30 kg.ha^{-1} P + 60 kg.ha^{-1} K and 90 kg.ha^{-1} N + 30 kg.ha^{-1} P + 60 kg.ha^{-1} K (7.93 and 7.88 t.ha^{-1} of dry mass) in our experiment. Significantly the highest amount of root biomass was produced on the grass swards fertilized with higher doses – 180 kg.ha^{-1} N + 30 kg.ha^{-1} P + 60 kg.ha^{-1} K (8.43 t.ha^{-1} of dry mass). Some stimulatory effect of nitrogen on root biomass production has been proved. The higher production of the root biomass may be related to intensive nitrogen fertilization. ZENIŠČEVA (1990) states that mineral nutrition, and nitrogen particularly stimulates root growth to a certain extent, but less intensively than aboveground biomass. Positive effect of nitrogen fertilization on root production of natural grass swards was confirmed in experiments published by ÚLEHLOVÁ (1990). The author has explained the increase of root biomass weight from 1.9 to 3 kg.m^{-2} after using 200 kg.ha^{-1} N by changes of grass swards species. HEJDUK, HRABĚ (2003) also observed the increase of belowground biomass production as a result of higher fertilizer doses. They quote the production 989 g.m^{-2} on non-fertilized sites, that means 92 g.m^{-2} (8.6 %) less than on fertilized ones (1081 g.m^{-2}). This difference is significant. On the contrary, KLAPP (1971) states that nitrogen deficiency or its appropriate supply influences favourable the root system growth and development, while intensive nitrogen fertilization results in root weight reduction. Also FIALA (1985, 2007) and MRKVIČKA, VESELÁ, SKÁLA (2004) quote the root biomass reduction on grass swards after the use of higher doses of nitrogen fertilization (200 kg.ha^{-1} N).

The higher production of root biomass is influenced by higher dose of nitrogen (180 kg.ha^{-1}) in our experiment is in agreement with the results published by VELICH (1986), HRABĚ, HALVA, ZIMOLKA (1989), TESAŘOVÁ (1990). The impact of nitrogen on increasing production of root mass also state JANČOVIČ (1985) and GREGOROVÁ, KEČKEMÉTHY, FUSKOVÁ (1989).

The year of cultivation has the additional influence on creation of root biomass. The agro-climate conditions constitute its influence, therefore more difficult to be manipulated by a farmer. We shall also focus on this aspect in the view of the fact that we encounter a threat of dry and wet years. A lot of remarkable results related to weather-standard years and extreme seasons (Tab. IV) have been achieved during 6-years research (1993–1998).

The results achieved in 1993, when the total precipitation amounted only 336.5 mm and 794.7 mm during the whole year, document the drought negative effect on root system of grass swards. The air temperature was 15.8 °C during the vegetation season and 9.0 °C during the whole year.

Robust of the root system, the depth of roots penetration into the soil profile and rooting density of the soil decide about the resistance of grass swards to droughts (except for the aboveground properties).

The largest amounts of root biomass (10.52–11.43 t.ha^{-1}) were detected in 1993 in three evaluated types of grassland. The production of root biomass is significantly higher during the climatically dry year than climatically normal and wet years. We observed the considerable root biomass reduction during the wet years 1995 and 1996, not only in comparison with the dry year but also with the standard climatic ones. Explained through the anatomical and morphological characteristics of the plant rooting adaptation to drought stress resulting in higher rooting creation – to the detriment of the aboveground vegetation parts, etc. The soil moisture deficit inhibits growth of assimilative bodies resulting in distribution of the assimilative bodies into the roots in preference. On the one hand, the adaptations reduce water loss by transpiration; on

IV: *The root biomass amount during the individual years (t.ha^{-1})*

Year	Total precipitation (mm)		Climatic year	Root biomass weight (t.ha^{-1})		
	IV–IX	I–XII		PG	OSG	TG
1993	336.5	794.7	dry	10.52 c	11.43 c	10.80 c
1994	564.7	917.3	standard	10.37 c	9.01 b	7.62 b
1995	568.3	935.7	wet	7.76 b	5.70 a	5.50 a
1996	630.9	971.3	wet	6.75 a	6.63 a	4.87 a
1997	402.8	765.8	standard	7.73 b	6.09 a	7.34 b
1998	494.8	829.7	standard	7.97 b	7.72 ab	7.73 b
Ø for 1951–2000	422.0	746.0				
LSD $\alpha_{0.05}$				0.93943	2.32865	1.66307

a, b, c, d – significant differences

the other hand, they are capable of gaining water from bigger depths, which enables growth under the soil moisture deficit conditions. KLAPP (1971), KOLEK, KOZINKA *et al*. (1988) report that robust root system having the larger adsorption surface ensures better water uptake and more nutrients taken from the bigger soil volume and depths under the drought conditions. GÁBORČÍK, KOHOUTEK, ILAVSKÁ (2007), FIALA, TŮMA, HOLUB (2012) also report that there is an increase in the grass swards root biomass under the precipitation deficit conditions. MATA–GONZALES, SOSEBEE, WAN (2002) evaluated production of roots and aboveground biomass of two species of thermophilic grasses (*Bouteloua gracilis* and *Hilaria mutica*) in irrigation and non-irrigation conditions. They conclude that more root biomass was created at low soil moisture, while more aboveground biomass was created at higher levels of irrigation.

The achieved results document that there has been some rooting stability in response to the drought stress. The aboveground part of swards with significant growth reduction responds to drought stress in a more sensitive way. We recorded the lowest production of aboveground biomass 4.43 $t.ha^{-1}$ in the year 1993 what was a climatically dry year (Tab. IV).

An important evaluation parameter of drought impact on the grassland is the ratio of root mass to above–ground parts of vegetation (R:S – root: shoot ratio, S – the average harvest of one cut), which is genetically fixed (RYCHNOVSKÁ *et al*., 1985). The R:S ratio is a measure of vegetation ability to avoid drought. The higher R:S values indicate that there has been a bigger vegetation drought resistance. Tab. III shows the R:S ratio.

There has been approximately equal R:S ratio on the TG and OSG, which amounts are 4.27 or 4.02. There has been the biggest R:S ratio on the PG (5.16) and evidently higher one in comparison with the OSG and TG. The results have documented a higher permanent grass swards ecological resistance to drought stress factor. Therefore, there has been good cause to believe that PG has been capable of tolerating global warming of the Earth and contribute to stability of the rural landscape.

The R:S ratio has also marked a substantial influence on grass swards mineral nutrition. There had been the R:S ratio (3.33 or 3.68) reaching evidently lower value in the variants fertilized by nitrogen in comparison with those not fertilized and those having $P_{30}K_{60}$ – 5.47. RYCHNOVSKÁ *et al*. (1985) publish the similar nitrogen fertilizing influence on the R:S ratio.

The maximum production of root mass was recorded in 1993, what also documents the largest ratio R:S with the value of 8.78 significantly higher than in others evaluated years. A high value of R:S (5.42) was recorded in 1998, highly significant compared to 1994 to 1997.

We also evaluated the turnover rate and turnover time of grassland root biomass. The average results for the years 1993–1998 are presented in Tab. V.

Turnover time of root biomass on PG took the longest time 3–5 years, balanced results were on OSG and TG, where the turnover time of root biomass took 2.5–3.4 respectively 2.5–3.5 years. FIALA, JAKRLOVÁ (1987) mentioned turnover time of underground biomass of association *Polygalo-Nardetum strictae* around two years, FIALA (1996) in vegetation of *Calamagrostis villosa* 3 years and in vegetation of *Avenella flexuosa* 1.6 year. GÁBORČÍK, KOHOUTEK, ILAVSKÁ (2007) recorded on PG of a northern Slovakia a shorter time of turnover time of root biomass (1.7–2.5 years) and conclude that the noticeable effect of mineral fertilization on the endpoint wasn't confirmed.

V: *Turnover rate and turnover time of grassland root biomass*

Grassland	Treatment	Turnover rate of root biomass (%)	Turnover period of root biomass (in years)
PG	1	28.25	3.54
	2	26.04	3.84
	3	26.60	3.76
	4	19.84	5.04
	Average	**26.60**	**3.76**
OSG	1	29.59	3.38
	2	39.68	2.52
	3	30.12	3.32
	4	34.48	2.90
	Average	**33.00**	**3.03**
TG	1	30.86	3.24
	2	28.65	3.49
	3	36.76	2.72
	4	39.37	2.54
	Average	**34.60**	**2.89**

In this contribution, we evaluate ecological significance of root biomass of grassland, and directly with it also goes assessing of tillering zone production and harvest of aboveground biomass (Tab. III).

Production of tillering zone was lower on OSG and TG (5.11 or 5.42 $t.ha^{-1}$), significantly higher on PG (5.72 $t.ha^{-1}$). We observed a significantly higher production of tillering zone with variants which were fertilized with nitrogen than on non-fertilized and PK fertilized. Climatic factors of years have also effect on production of tillering zone (rainfall, air temperature), the lowest production was noticed in 1995 and 1996, significantly higher in 1993.

The lowest harvests of aboveground biomass were noticed on TG (5.80 $t.ha^{-1}$), significantly higher on PG and OSG (6.35 or 6.54 $t.ha^{-1}$). Mineral nutrition had a significant impact on production of aboveground biomass. Harvests were relatively low on non-fertilized control and PK fertilized variant (4.67 or 5.03 $t.ha^{-1}$), fertilization with nitrogen significantly increased a harvest (7.09–8.13 $t.ha^{-1}$). The positive influence of nitrogen fertilization on the growth of grassland harvest also confirmed JANČOVIČ (1999), MRKVIČKA, VESELÁ (2001, 2002), ILAVSKÁ, RATAJ, STYPIŇSKI (2000) and others. These authors indicated on non-fertilized control PG harvests of 2.252 $t.ha^{-1,}$ with influence of nitrogen fertilization (90 and 180 $kg.ha^{-1}$ N + PK) the harvest increased at 5.725 or 7.318 $t.ha^{-1}$ of dry mass. Harvests increasing influencing with graded doses of mineral nutrients were also recorded on over-sown and temporary grassland. The positive influence of nitrogen fertilization (100 $kg.ha^{-1}$ N + PK, 200 $kg.ha^{-1}$ N + PK) on an amount of sward harvests are also presented by VESELÁ, MRKVIČKA (2002). Compared to a harvest on non-fertilized control (2.64 $t.ha^{-1}$) was the harvest on fertilized variants increased at 4.61 or 5.38 $t.ha^{-1.}$ A significant influence of years was also confirmed, the lowest harvests were indicated during a climatically dry year 1993 (4.43 $t.ha^{-1}$), the significantly highest were in the years 1994, 1996 and 1997 (7.30–7.72 $t.ha^{-1}$).

We recorded the highest production of total biomass on PG (20.58 $t.ha^{-1}$), significantly the lowest production on TG (18.53 $t.ha^{-1}$). Graded doses of N fertilizers significantly increased the primary production of grassland. A significant influence of years was also confirmed, the highest production of total biomass was in a climatically dry year 1993 (23.59 $t.ha^{-1}$), where a low harvest of aboveground biomass (4.43 $t.ha^{-1}$) compensates the increased production of root biomass (10.92 $t.ha^{-1}$).

CONCLUSIONS

Root biomass has a significant share in the total grassland biomass (49.9–54.2 %), followed by tillering zone (33.3–36 %) and with the lowest share of aboveground biomass (11.9–16.8 %).

The lowest amounts of the root biomass were recorded on the temporary grassland – 7.31 $t.ha^{-1}$ of dry mass, higher amounts on the over-sown grassland – 7.76 $t.ha^{-1}$ and the significantly highest amounts on permanent grassland – 8.52 $t.ha^{-1}$ of dry mass of root biomass.

The specific nitrogen stimulating influence on root biomass production has been proven. A significantly the highest root biomass amount was created on the grasslands fertilized at higher doses – 180 $kg.ha^{-1}$ N + 30 $kg.ha^{-1}$ P + 60 $kg.ha^{-1}$ K (8.43 $t.ha^{-1}$ of dry mass).

The production of root biomass was a significantly higher during dry years 1993 than in climatically normal and wet years.

R:S ratio of the assessed grasslands achieved the values from 4.02 to 5.16. Higher values on PG (5.16) indicate its higher drought resistance.

Turnover time of root biomass was the longest on PG 3.5–5.0 years, balanced results were recorded on OSG and TG (2.5–3.5 years).

Dominant share of root biomass and tillering zone in the total plant biomass provides significant extra-productive functions of grasslands that contribute to the stability of the agricultural landscape.

SUMMARY

An aim of the work was production assessment of aboveground biomass, tillering zone and underground biomass on three types of grasslands – permanent grassland (PG), over-sown grassland (OSG) and temporary grassland (TG) in sub-mountain area of central Slovakia. There were applied four levels of mineral nutrition in each grassland (non-fertilized variant, var. 30 $kg.ha^{-1}$ P and 60 $kg.ha^{-1}$ K, var. 90 $kg.ha^{-1}$ N + $P_{30}K_{60}$, var. 180 $kg.ha^{-1}$ N + $P_{30}K_{60}$). Sampling of roots and tillering zone of grass swards was realized by method of monoliths sampling with the steel rollers. The root biomass has the most significant share in the total biomass of grasslands (49.9–54.2 %), followed by tillering zone (33.3–36 %) and with the lowest share of aboveground biomass (11.9–16.8 %). A dominant share of root biomass and tillering zone ensure significant extra-productive functions of grasslands that contribute to the stability of agriculture landscape. We recorded the lowest amounts of root mass on TG (7.31 $t.ha^{-1}$), or OSG (7.76 $t.ha^{-1}$), the highest amounts on PG (8.52 $t.ha^{-1}$, LSD $\alpha_{0.05} = 0.715$). The specific nitrogen stimulating influence on root biomass production has been proven. A significantly the highest root biomass amount was created on the grasslands fertilized at higher doses – 180 $kg.ha^{-1}$ N + 30 $kg.ha^{-1}$ P + 60 $kg.ha^{-1}$ K (8.43 $t.ha^{-1}$ of dry mass, LSD $\alpha_{0.05} = 0.826$). Production of tillering zone was lower on OSG and TG (5.11 or 5.42 $t.ha^{-1}$), significantly higher on PG (5.72 $t.ha^{-1}$,

LSD α $_{0.05}$ = 0.524). We observed a significantly higher production of tillering zone with variants which were fertilized with nitrogen than on non-fertilized and PK fertilized (LSD α $_{0.05}$ = 0.605). The lowest harvests of aboveground biomass were noticed on TG (5.80 $t.ha^{-1}$), significantly higher on PG and OSG (6.35 or 6.54 $t.ha^{-1}$, LSD α $_{0.05}$ = 0.458). Mineral nutrition had a significant impact on production of aboveground biomass. Harvests were relatively low on non-fertilized control and PK fertilized variant (4.67 or 5.03 $t.ha^{-1}$), fertilization with nitrogen significantly increased a harvest (7.09–8.13 $t.ha^{-1}$, LSD α $_{0.05}$ = 0.529). We recorded the highest production of total biomass on PG (20.58 $t.ha^{-1}$), the lowest production on TG (18.53 $t.ha^{-1}$, LSD α $_{0.05}$ = 1.237). Graded doses of N fertilizers significantly increased the primary production of grassland (LSD α $_{0.05}$ = 1.428). We also evaluated R:S ratio and turnover time of root biomass. R:S ratio of the assessed grasslands achieved the values from 4.02 to 5.16. Higher values on PG (5.16) indicate its higher drought resistance. Turnover time of root biomass was the longest on PG 3.5–5.0 years, balanced results were recorded on OSG and TG (2.5–3.5 years). Based on achieved results, we recommend using the fodder plants cultivation system on PG or OSG. Permanent grasslands were proved as ecologically more stable and more resistant to drought as temporary grasslands; they can together with optimal mineral nutrition provide adequate production of root biomass (8.5 $t.ha^{-1}$) and a harvest of aboveground biomass (6.3 $t.ha^{-1}$). The cultivation system of TG is economically more difficult and disturbs dynamic balance of the ecosystem. The amount of underground and aboveground biomass has significantly reduced on temporary grassland (7.3 $t.ha^{-1}$ or 5.8 $t.ha^{-1}$) in comparison with permanent grassland.

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Address

Ing. Ján Tomaškin, PhD., RNDr. Judita Tomaškinová, PhD., Department of environmental management, Faculty of Natural Sciences, University Matej Bel University, Tajovského 40, 974 01 Banská Bystrica, Slovak Republic, prof. Ing. Ján Jančovič, PhD., doc. Ing. Ľuboš Vozár, PhD., Department of grassland ecosystems and forage crops, Fakulty of agrobiology and food resources, Slovak University of agriculture in Nitra, Tr. A. Hlinku 2, 949 76 Nitra, Slovak Republic, e-mail: jan.tomaskin@umb.sk, judita.tomaskinova@umb.sk, Jan.Jancovic@uniag.sk, Lubos.Vozar@uniag.sk